EUROPEAN
GEOPHYSICAL
SOCIETY

European Geophysical Society

Annales Geophysicae

Part II

Hydrology, Oceans, Atmosphere
& Nonlinear Geophysics

Supplement II to Volume 15

Editorial

Traditionally all abstracts of contributions submitted to the 22nd General Assembly are included free of charge in the *Abstract Book* once they were accepted by the appropriate convener(s) and once they were received by February 1997, i.e., about two months *after* the deadline, and in the standard format and of sufficient quality for reproduction. Abstracts submitted for symposia sponsored by two Sections included in different parts of the *Abstract Book* are included (twice) in both parts, respectively.

Like in previous years, not all contributions included will actually be presented. Because of the lack of financial support, several young scientists as well as colleagues from the central and east-European countries will not be able to participate in the meeting, although the Society has continued its support schemes, such as the Young Scientists' Travel Award and the East European Support Award. In this way there are more abstracts included in the *Abstract Book* than contributions compiled in the *Programme Book*. Therefore, in order to simplify the ordering of abstracts within a symposium, we have adopted the alphabetical order with respect to the surname of the first author rather than the order of presentation.

With more than 4.300 contributions received, the *Abstract Book* has become an open forum for fast distribution of results of geophysical research on a pan-European, international level, helping, at the same time, to promote the contact between all geophysicists in Europe. Please, support the fostering of cooperation and contact your colleagues also if not personally present this time.

On behalf of the Society I am very pleased to welcome you to Vienna on the occasion of the 22nd General Assembly of the European Geophysical Society. May your participation in this meeting be successful and scientifically rewarding.

A.K. Richter
Executive Secretary

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	20 May 1997	Conference Proceedings

4. TITLE AND SUBTITLE

Geophysics including meteorology, ionospheric physics, space physics, geochemistry, seismology, paleo magnetism, plate tectonics

5. FUNDING NUMBERS

F6170897W0116

6. AUTHOR(S)

Conference Committee

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Rutherford Appleton Laboratory
Chilton, Didcot OX11 0QX
United Kingdom

8. PERFORMING ORGANIZATION REPORT NUMBER

N/A

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

EOARD
PSC 802 BOX 14
FPO 09499-0200

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

CSP 97-1048

11. SUPPLEMENTARY NOTES

3 Volumes plus a newsletter.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

A

13. ABSTRACT (Maximum 200 words)

The Final Proceedings for European Geophysical Society XXII General Assembly, 21 April 1997 - 25 April 1997

The Topics covered include: Geophysics including meteorology, ionospheric physics, space physics, geochemistry, seismology, paleo magnetism, plate tectonics

19971022 074

14. SUBJECT TERMS

Space Science, Geophysics, Remote Sensing, Space Environment

15. NUMBER OF PAGES

908

16. PRICE CODE

N/A

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19, SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

CONTENTS

Part I: Society Symposia, Solid Earth Geophysics & Natural Hazards

I.3. GEODESY (G)

I.4. NATURAL HAZARDS (NH)

PART II Hydrology, Oceans & Atmosphere & Nonlinear Geophysics

II.1. HYDROLOGICAL SCIENCES (HS)

II.2. BIOSPHERIC ASPECTS OF THE HYDROLOGICAL CYCLE (BAHC)

II.3. OCEANS & ATMOSPHERE (OA)

III.2. PLANETARY AND SOLAR SYSTEM SCIENCES (PS)

HYDROLOGICAL SCIENCES (HS)

HS2 Open session on hydrology

Convener: O'Kane, J.P.

DENSITY-DRIVEN CIRCULATIONS IN ATOLL CARBONATE PLATFORMS.

D. Broc (CEA/DRN/DMT/SEMT/TTMF CEN Saclay, 91191 Gif sur Yvette, France)
A.M. Leclerc and P. Jean-Baptiste (LMCE-Laboratoire de Modélisation du Climat et de l'Environnement CEN Saclay Bat. 709, 91191 Gif sur Yvette, France)

The composition and circulation of interstitial waters in the porous carbonate framework of coral reefs are central to our understanding of their development and geological evolution. Groundwater flow in an idealized atoll platform is simulated with CASTEM, a computer code developed at the CEA. Coupled Darcy's law and equation of transport (diffusion-dispersion-convection) are solved by the mixed & hybrid finite element method. Inward and upward circulations of oceanic water are shown to occur and account for the negative temperature gradient indicated by field data. These steady-state circulations are due to temperature and to a lesser extend salinity gradients. The role of the different permanent driving forces of the flow is discussed and enlightened with 1D analytical calculations. Two indurated dolomitic horizons are defined, one at the base of the carbonate structure and a second one closer to sea surface : the near surface carbonate edifice is deprived of a significant portion of the flow by the occurrence of the secondary upper karstic layer. Thus an upper limit of the possible flow rate is calculated. Finally, an estimate of the maximum nutrient fluxes (PO_4 and NO_3) transiting through the platform is compared with the expected needs of the surface ecosystem.

\N ARTIFICIAL NEURAL NETWORK APPROACH TO \AINFALL-RUNOFF MODELLING

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R.L.Wilby (Department of Geography, University of Derby, Kedleston Road, Derby, DE22 1GB, UK)

This paper provides a discussion of the development and application of artificial neural networks (ANN) to flow forecasting in two flood prone UK catchments using real hydrometric data. Given relatively brief calibration data sets it was possible to construct robust models of 15 minute flows with 6 hour lead times for the Rivers Amber and Mole. Comparisons were made between the performance of the ANN and conventional flood forecasting systems. The results obtained for validation forecasts were of comparable quality to those obtained from operational systems in the River Amber.The ability of the ANN to utilise missing data 'flags' as input and to 'learn' from the event currently being forecasted in real-time makes it an appealing alternative to conventional lumped or semi-distributed flood forecasting models. However, further research is required to determine the optimum ANN training period for given catchment, climatic and seasonal contexts.

MATHEMATICAL MODEL FOR LOAD TRANSPORT IN SELECTED COASTAL AREA.

U.Bethers, J.Sennikovs, Laboratory for Mathematical Modelling of Environmental and Technological Processes, University of Latvia.

A longshore load transport along the sandy coastline of Latvia (i.e. eastern coast of Baltic Proper) is important feature of this area. Prevailing south and south-west winds during the autumn-winter storm periods cause the annual northward sand transport up to 1 million cub.m. This results in both regular and permanent changes in the bottom geomorphology. Besides natural aspects, load transport influences the harbour industry via sand deposition in sea entrance channels.
The unsteady system of two-dimensional mathematical models for wave, hydrodynamical fields and load (bed and suspended) transport is developed for the 15 km long particular coastal zone including harbour Ventspils. It allows hind- and forecasting of the development of depth distribution.
The model results have indicated good quantitative and qualitative agreement with the depth surveys performed before and after storm periods. Typical periods between such periods are about one month. The comparison of the long-time sedimentation hindcasts with the annual dredgework's volume has shown the ability of the model to forecast the deposition amount in characteristic and critical seasons and years. The net volumes and direction of the annual sand transport predicted by the model is in principal agreement with integral estimations by means of engineering methods.

INDIRECT ESTIMATION OF SOIL MOISTURE FROM ENERGY BALANCE: PRELIMINARY RES ULTS

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Estimation of time-varying soil moisture state is a key step in the solution of many hydrological problems, but hard to achieve by direct (sparse) or indirect (largely inaccurate) measurements. On the other hand, soil temperature may be considered as a much more reliable and commonly available indicator of the soil state (e. g. from remote sensing). An indirect estimation method for soil moisture is then proposed. On the basis of the surface energy balance, a new model is formulated relating the soil relative humidity to incoming solar radiation, wind speed, air and soil temperatures. For each site surface albedo and emissivity parameters are assigned based on soil type and land use. Model's tests have been preliminary conducted using data from the Oklahoma Mesonet Sites, analysing the soil moisture space-time dynamics. The model correctly discriminates the periods where the evaporation regime is either energy limited or water limited and soil/vegetation controlled. Further tests on the model's accuracy are being conducted using the AMS data sets acquired during the 1987-1989 FIFE experiments, for which direct measurements of soil moisture are also available.

SIMULATION OF THE GLOBAL WATER BALANCE USING THE ISBA LAND-SURFACE SCHEME IN STAND-ALONE AND ASSIMILATION MODES

Hervé Douville, Eric Bazile, Dominique Giard, Joël Noilhan
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In the framework of the international GSWP project, the ISBA land-surface scheme of Météo-France has been forced with meteorological observations and analyses in order to study the feasibility of producing a global soil wetness climatology at a $1^\circ \times 1^\circ$ resolution. A control experiment has been performed over the period 1987-1988, using the ISLSCP Initiative I boundary conditions. The soil wetness index and snow cover distributions have been compared respectively to the results of the ECMWF reanalysis and to satellite observations. A regional validation of the simulated runoff has been attempted against the GRDC river flow climatology. Besides the control run, other simulations have been performed in order to study the sensitivity of the hydrologic budget to changes in the surface parameters, the precipitation forcing and the runoff scheme. Such modifications have a significant impact on the partition of total precipitation into evaporation and runoff, thus suggesting that any computed soil wetness climatology must be considered with great caution. In order to get more reliable results, an off-line assimilation technique has been tested, in which soil moisture is corrected by iterative comparison between simulated and observed near-surface air temperature and humidity.

CONTROL AND VALIDATION OF WATER QUALITY DATA SERIES

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French administration regulation imposes continuous monitoring of aquatic environment at every river site equipped with a plant. Therefore «Electricité de France» performs continuous data aquisition of four variables: temperature, electrical conductivity, dissolved oxygen, pH on an hourly basis. Several different kind of models were elaborated for each parameter in order to be able to control and validate these data. These tools are based on statistical (probability, autoregressive (AR) or autoregressive model with exogenous inputs (ARX), artificial neural networks (ANNs), statistical fit to physical laws) and physical concepts (water-atmosphere exchange, biology-chemistry conection).
A method is presented which combines the results of different models with weights adapted consequently. Each model has specific performances when it is calibrated, and has a specific sensitivity to each perturbation that can occur.

APPLICATION OF NEURAL NETWORKS TO MODELLING STREAM pH

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Stream water pH is controlled by numerous processes: biological, physical and geochemical. Examples are: CO_2 pressure equilibrium with atmosphere, plant photosynthesis and respiration, organic matter degradation, geological and mineral background, pollution, etc. Inter-relationships between those processes and pH values are complex, non-linear and not all sorted out. This is the reason why the neural network approach has been tested for pH modelling.
The case study concerns a mesurement site upstream of a power plant, the Loire river in France. Daily values of pH, stream discharge and solar irradiation are available.The model is a multi-layer neural network of the perceptron type. Several architectures have been tested as well as transformation of input variables. When calibrated over three years and validation on two years independent samples, the model has proved satisfactory on ph simulation.The model will be used for on line control and screening of pH measurements.

APPLICATION OF GLOBAL OPTIMISATION TECHNIQUES TO THE CALIBRATION OF CONCEPTUAL RAINFALL RUNOFF MODELS

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Conceptual rainfall runoff models (CRRMs) generally have a large number of parameters and the accuracy of their calculations depends on how the relevant parameters are defined. However, because of their conceptual nature, these parameters cannot be measured directly and are therefore estimated on the basis of a calibration process i.e. minimising an objective function (OF). The search for the minimum of the OF in the case of CRRMs is, however, somewhat complex. Recently many researchers have turned their attention to the use of global optimisation methods. Duan et al. have presented a global optimisation method called SCE-UA. Another possible technique is offered by the genetic algorithm (GA) coupled with local-search optimisation techniques which perform the subsequent "fine-tuning" process. We present the results of the comparison between different structures of GA coupled with a SQP algorithm and the SCE-UA. The analyses were conducted using a CRRM called ADM, whose structure is similar to many other well known CRRMs, applied both to a single basin and to a complex basin composed of three sub-basins. For both types of basins, we considered a theoretical case, without model and data errors, in which the true value of the parameters is known a priori, and one or two cases of the real world where model and data errors exist.

OPTIMISATION OF SPATIAL CORRELATION IN PRECIPITATION DATA ANALYSIS

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The geostatistical approach is a successful way of treating problems too complex for an analytical approach. A typical situation in data-analysis is, that the interest is in an areas amount of parameters but only pointwise measurements are available. The statistical parameter that gives way from point-data to area-data is the spatial correlation of the point-data.

For practical treatment the statistical correlation of the point-data has to be replaced by a correlation function $\rho(h)$, that defines the spatial correlation depending on the distance of any two points of the area. This is traditionally done with a translation-invariant function, though this invariance is not found in the measured data.

In this work an optimisation of the fitted function is reached by transforming the geographical domain x into a high-dimensional domain x´. The transformation depends on additional geographic parameters like height and slope of the terrain and is controlled by parameters p_i regulating deformations in it. The function $\rho(h)$ is then fitted in the domain x´ and optimised by the choice of the p_i.

This method achieves a significant improvement of the correlation function $\rho(h)$, which has influence on further data-treatment like the estimation and simulation of areal precipitation.

Evaluation of Speeds of Interaction in the System Rock-Water in the Earth Crust by the Uranium Isotops.

Georgij P. Kiselev

The natural Uranium isotops in the fluids of the Earth Crust are cionsidered as indicators of geological processes. The formation of its concentration and interconnection is a subject depending of the physical regulations of nuclear desintegration and physical-chemical processes in a system "rock-water". An author represents a mathematical method of account of the comparison of speeds of the transition of Uranium atoms in the same processes. The measurement of the speed of physical-cemical processes in the Earth Crust is based on the speed of nuclear desintegration. There is found the transition from atoms' level to local, regional and global levels. It gaves the opportunity to account the contemporary speeds of the processes of interconnections within the system "rock-water".

CHANNEL NETWORK ANALYSIS

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Dynamic 'living' computer maps is needed in cases of Extremal Ecological Situations, connected with water polutions (Oil) for visualisation of pollutant transport processes in river systems of any structure. Moreover, those maps may be used in regional rivernet monitoring. The main purpose is to make computer tool - simulation model for Channel Network Analysis (CNA) with easy visible presentation of water pollution in tasks of monitoring and prognozis of water ecology catastrofes. Movement of various liquid pollutions may be seen at each time interval is shown concentration of any pollutant on each river fragment for all river network (in different coloures connected with the part of maximal possible concentration). Precipitation and main elements of water balance are also included. In the range of versions of different level are realized input of rivernet of various structure immediatelely at display from keyboard. River net has about 5000 elementary fragments with a length depended of scale. Location of waste disposal place and the regime of wastes, location of towns are done by cursor moving. It is possible to estimate some types of pollutants with the range of physical and chemical on different independent channels (2-5 and more), with various parameters of stability, mobility etc. Special version is intended for estimation of prognozis and for screen presentation of Oil spill (Ufa River, the beginning of 1996). The Oil spill was under ice and was partly delayed by it . Parameters of oil movements were changed in time (winter, spring). Water and temperature regimes was given by various scenarious.

APPLICATION OF THE PROTON MAGNETIC RESONANCE METHOD TO GROUNDWATER INVESTIGATIONS

A. LEGCHENKO, A. BEAUCE, P. VALLA
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J. BERNARD (IRIS INSTRUMENTS ORLEANS, FRANCE)

The Proton Magnetic Resonance method (PMR), also known as the Nuclear Magnetic Resonance method (NMR), is a property of Hydrogen protons which produce a magnetic field when they are excited by an alternative field in the presence of a static magnetic field. Most Hydrogen atoms located in the ground coming from water molecules, the direct detection of water can be envisioned from surface measurements with such a method.

In PMR, the static field is the Earth's magnetic field, and the dynamic field is produced by a current into a loop laid as the surface of the ground, at the precession frequency of the protons. The amplitude of the relaxation field after the pulse of current has been switched off, is proportional to the water content. The time constant of the decay is related to the mean pore size of the aquifers. Experimental results will be presented.

THREE-DIMENSIONAL GEOSTATISTICAL ANALYSIS OF HYDRAULIC CONDUCTIVITY AND PARTICLE-SIZE IN A FLUVIAL SAND

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S. Ferson and N. Vandenberghe (Institute of Earth Sciences, KULeuven, Redingenstraat 16, B-3000 Leuven, Belgium)

Fluvial sands in the Campine region in Belgium were the subject of a detailed geostatistical analysis. The saturated hydraulic conductivity, K_s, and particle -size were determined on 100 cm³ soil cores collected along two perpendicular transects of 280 and 165 m length, respectively. The sampling interval along the transects was 5 m. At the intersection of the two horizontal transects, a vertical core of 7.8 m length was sampled for K_s and particle-size every 0.1 m. Values of K_s were negatively correlated with percentage clay and silt and positively correlated with percentage sand. Stationarity of the variance for K_s and particle-size values was checked by constructing median versus interquartile range squared plots. Variance stabilizing effects were evident when a logarithmic transformation of K_s was used. Semi-variograms were subsequently determined for $\log_e$-transformed K_s for all three transects. Based on four directional semivariograms at angels of 0, 45, 90, and 135 degrees, a strong anisotropy effect was found in the horizontal plane. The estimated range of spatial correlation based on the two-dimensional mean isotropic semivariograms was 50 m, based on a spherical model. A similar analysis for the vertical transect resulted into a spatial range of 1.5 m, also based on a spherical model. Variogram analyses indicated that marked similarities in spatial structure exist between K_s and particle size. Finally, experimental cross-semivariograms between $\ln(K_s)$ and selected particle-size parameters were constructed and could be well described by means of sperical models.

DETERMINATION OF SATURATED HYDRAULIC CONDUCTIVITY FROM GRAIN-SIZE DISTRIBUTION

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Saturated hydraulic conductivity and grain-size distribution were measured on soil cores collected from fluvial sands in the Campine region of Belgium. Conductivity was determined from constant head permeameter measurements whereas grain-size distribution (32 classes) was obtained with laser-technology. These data were collected for two horizontal and perpendicular transects comprising 166 measurement points and one vertical transect of 7.8 m deep with 56 observations. Hydraulic conductivity was determined from grain-size distribution using empirical and statistical models. We tested the predictive capability of eight different empirical models which used as predictor variable either a single grain-size distribution parameter (d_{10}, d_{50}, median particle size, etc.) or a combination of those parameters and porosity estimates. Two types of statistical models were evaluated. The first one is based on a simple linear regression analysis between conductivity and cumulative percentages of particle-size. The second type uses several particle sizes in a multiple linear regression combined with principal component analysis (PCA). Differences in performance between the eight empirical models were small. The best model (r = 0.498) is based on that of Fair and Hatch (1933) and uses information from all grain-size classes. The best statistical model (multiple regression and PCA) was obtained when five grain-size classes were used for the horizontal data set (r=0.685) and when four grain-size classes were used for the vertical data set (r= 0.907).

SOIL MOISTURE RETRIEVAL FROM MULTI-FREQUENCY RADAR DATA AT FIELD AND CATCHMENT SCALES

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The possibility of estimating soil moisture on bare-soil fields by means of active microwave sensors is investigated. Time domain reflectometry (TDR) ground measurements of soil moisture and C- and L-band synthetic aperture radar (SAR) images were collected during a NASA SIR-C/X-SAR campaign in April 1994 for a small catchment in Toscana, Italy. A theoretical surface scattering model is applied to the radar data to obtain estimates of soil moisture. These are compared with the ground measurements and with interpolated results based on simulation with a distributed hydrologic model calibrated with the ground data. Having implemented a procedure for the compensation of the image georeferecing error, the comparison of single field-average values yields a fair agreement between the three types of soil moisture estimates, without significant differences in the results between the C and L bands. Poor agreement was obtained at the catchment scale, owing to strong variability in topography and land cover. Suggestions are made for combining information from ground measurement, hydrologic model, and SAR inversion to overcome limitations of each type of soil moisture estimator for large scale applications.

REGIONALIZATION OF DAILY PRECIPITATION STOCHASTIC MODEL PARAMETERS. APPLICATION TO THE GUADALQUIVIR VALLEY IN SOUTHERN SPAIN

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The knowledge of rainfall spatial distribution is necessary to determine the water processes in a hydrologic basin. However, available data are very scarces and some methodology has to be developped in order to get some conclusions about precipitation at any point of the basin from a few meteorological stations.
Initially, some authors worked with some interpolation methods applied to basic characteristics of the series: mean annual precipitation and mean annual number of wet days. Later, estimation variables were seasonal model parameters applied in points with meteorological records. However, results they got were not good.
In this work, we have followed with the last mentioned research, but we have defined a new concept of "proximity" between meteorological stations in order to estimate the parameters of the model. Then, "proximity" is refered to the best variable, climatic or geografic, related with this parameter or cofficient. Multiple relationships have been also tested, concluding that the latter are better than the simple one. For the Guadalquivir Valley, a linear regression with the distance to the sea, the mean annual precipitation and the mean precipitation on wet days is recommended.

THERMAL POLLUTION MODELLING - AN INSTRUMENT FOR WATER QUALITY MANAGEMENT

Eng. **Maria-Cristina RADUCU** -
National Institute of Meteorology and Hydrology

This research tried to accomplish the modelling of thermal pollution phenomenon on the river Jiu, a Romanian affluent of the Danube, on a river reach of 137 km. The water overflowed by the thermo-power stations represent the greater warm source of the river, that is used to the water cooling equipements.
Carrying out the mathematical model we get informations about the evolution temperature of downstream of the thermo-power stations and we have the possibility to know the exceeding time of the limit values.
The basic structure of this model is represented by a thermal model coupled with a chemical model. The temperature modelling was achieved taking into account the hypothesis of a monodimension system in which the heat transfer is an advective process. The equations must be discretized in order to obtain a numerical solution.
Drawing some scenarios one can estimate the influence of the power stations on the water quality for different hypothesis of function. It can be also used like a prediction instrument concerning the environment evolution.

ΓERIA TRANSPORT IN POROUS MEDIA

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port of bacteria in heterogeneous saturated porous media has been .d experimentally using a novel fluorescent microscopic imaging ı technique. The approach involves 3D dynamic visualization and ification of bacteria distributions within a refractive index-matched s system. The experimental setup consists of a transparent porous ın packed with clear mineral particles of various shapes and sizes in ueous sucrose-added fluid. The refractive index-matching allows ·ptical probing at any point within the porous system. By staining ı and illuminating the porous regions within the column with a :heet of laser beam, bacteria transport through the porous medium observed and measured microscopically. A computer controlled ımera is used to record the fluorescent images at every vertical ıcation while sweeping back and forth across the column. These are then digitized and accumulated over a 3D volume within the :olumn. Several bacteria were selected and tested for survivability wth under our system's environment. Most bacteria appeared to and function normally under these conditions (e.g., sucrose for refractive index matching and staining for fluorescent). Experiments were performed with a selected bacterium. The provide a unique in-pore dynamic information on bacteria as a function of porosity, grain heterogeneity, and flow velocity.

THE EFFECT OF HETEROGENIETIES OF AQUIFERS ON WATER FLOW AND SOLUTE TRANSPORT CALCULATED WITH THE PARALLEL FE-PROGRAM *TRACE*

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The use of FE-programs is a common way to calculate water flow and solute transport in soils and aquifers. However the size of problems which can be handled numerically is often limited by computer memory capacity.
This problem becomes even more importance when calculating water flow and solute transport with heterogeneous defined aquifer and sorption properties, generated by stochastic algorithms.
In the presentation we will first present a method based on *domain decomposition* to solve the problem in calculating water flow and solute transport with heterogeneous defined aquifer and sorption properties. This method was implemented in a 3D transport code for executing on MIMD supercomputers. First the code ran on an Intel Paragon and is now adapted to a Cray T3E, utilizing up to 512 processing elements.
In the second part of the presentation we will focus on qualifying the effect of heterogeniety of aquifer and sorption parameters on water flow and solute transport.

ESTIMATION OF THE INFILTRATION AND RECHARGE PROPERTIES UNDER IRRIGATION FIELD

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J. Worm (Faculty of Earth Sciences, Free University, Amsterdam, De Boelelaan 1085, 1081 HV Amsterdam, The Netherlands)

This paper contains the results of studies made on the mechanism of artificial groundwater recharge and discharge. The approach is to chart moisture transfers from the surface, through the unsaturated zone, across the water table and into the groundwater flow system. The parameters that control the ingratiated saturated-unsaturated flow system are: the rate and duration of rainfall or evaporation at the upper boundary, the groundwater recharge or discharge rate, the antecedent soil moisture conditions and water table depth, the allowable depth of ponding, and the hydrologic properties of the soil. Experiments were carried out on a instrumented study site in the southern part of Taiwan. Further, laboratory analyses were done to calibrate the actual field conditions.

MAPS OF REGIONAL EVAPOTRANSPIRATION IN NORTHERN SWITZERLAND

M. Rohmann, L. Menzel and H. Lang (Institute of Geography – Hydrology Section – Swiss Federal Institute of Technology (ETH), Zürich, Switzerland)

Knowledge of evapotranspiration from land surfaces is important for a variety of water resource analyses. However, spatial information on evapotranspiration is rare for Switzerland. In this study we present contour maps of mean evapotranspiration (1973-1992) that we developed for the northern part of Switzerland. Both automated computational techniques and manual contouring were used for generation of the maps.
Based on the data of 28 catchments in the lowlands and the prealpine regions of northern Switzerland a relation was developed between mean temperature, mean precipitation and mean runoff. This relationship was applied to the dense network of precipitation stations and a 2 km grid of interpolated precipitation data. In combination with measured or interpolated temperatures a theoretical runoff value was derived for every precipitation station and grid point, respectively. Mean evapotranspiration was then calculated using the simple water balance equation. Finally, these data were used as reference values for the manually contoured maps and the automated mapping procedure.
Both maps show the expected patterns of spatial variations of evapotranspiration in the northern part of Switzerland. They compare well with results derived from existing point studies. The maps are part of a complete presentation of evapotranspiration over Switzerland.

MULTISITE CONCEPTUALLY-BASED MODELLING OF MONTHLY RUNOFF

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Generation of runoff sequences for simulation of complex water resources systems requires the use of multivariate stochastic models. To face the many practical difficulties existing with the building of pure multivariate ARMA type of models , contemporaneo us-ARMA (CARMA) models were developed (Salas et al., 1980). A conceptual stochas tic ARMA univariate framework for monthly streamflows, proposed by Claps et al. (1993), is adopted here as the base model for the multisite contemporaneous runo ff modelling. I n that framework, ARMA parameters have conceptual meaning and model residual rep resents the effective rainfall process. Our multisite model structure takes adva ntage of this analogy and considers the effective rainfall as the variable of wh ich the spatial correlation structure is analysed and reproduced, in agreement with the climati c evidence. Evaluation of the correlation structure of this process, which has f inite probability to present zero values, requires the use of an appro priate technique to deal with the contemporaneous presence of zeros throughout t he stations. Moreover, the presence of uneven time series, that normally makes t he multivariate analysis particularly arduous, is explicitly accounted for. Conc eptually-sound runoff model parameters and climatically-aware residuals are features that ensur e to the presented multisite framework parsimony in the model parameters and a s ignificant potential for its application in systems with inadequate runoff data or even ungauge d sections.

A MODELLING SYSTEM FOR CALCULATING SOIL WATER DYNAMICS AND EVAPOTRANSPIRATION

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Within the hydrological scientific community there exist a lot of computer models for simulating soil water dynamics and evapotranspiration of various landscape areas on different scales. The mathematical description of the processes in this models are based on several concepts and equations at different complexity. Every concept or equation has its specific restrictions regarding the requirements of input data and the accuracy of the various results. Using alternative submodels based upon different concepts and equations is essential for an efficient research especially in the context of GIS-based regional model calculations. In this paper a modelling system is presented, which consists different submodels from the sections atmosphere, plant and soil. The section atmosphere includes several formulas for calculating daily rates of potential evapotranspiration. The section plant consists three submodels at different complexity for determining the influence of vegetation cover on the process of evapotranspiration. The section soil includes a one layer- and a multiple layer plate-theory approach and a model based on the RICHARDS-equation for simulating soil water dynamics. Within this system these submodels can combined at will to build up a modelling approach for simulating soil water dynamics and evapotranspiration either on field or on regional scale. With that these approaches can also be accomodated at the given data base and the objectives. The modelling on regional scale is based on digital maps from the sections soil and landuse stored within a GIS, which is connected to the modelling system with the help of an interface.

HS3 Resolving salt accumulation and its control in irrigated soils

Convener: Gowing, J.

LAND SALINIZATION IN HUNGARY: A CASE STUDY

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At present more than 15% of Hungary's agricultural land (c. 1 million hectares) is affected by salinity. Salinization is caused by a complex link of physical, climatic, technical and socio-economic factors. Among the former (1) the closed flat character of the Carpathian basin to which the territory of Hungary belongs, (2) presence of thick salty Tertiary and Quaternary subsurface layers, and (3) stagnant, salty groundwater which can rise rapidly to the surface during rainy periods, seem to be most important.

Inappropriate irrigation practices have led to severe secondary salinization of soils. A strong decreasing trend in precipitation with the rate of up to 2-2.5 mm/yr is characteristic of most of the country's territory for the last century. Due to specific hydrologic conditions in the area, irrigation seems to be most efficient to remove the threat of drought. For the last 40 years irrigated area has increased 7 times. Today some 200,000 ha are under some form of irrigation, but more than 2 mill. ha could be irrigated economically.

Coordinated multidisciplinary strategies to predict and control salinization and prevent further land losses, which are suitable for the situation of rapid increase in irrigation, are discussed.

DRAINAGE DESIGN FOR SALINITY CONTROL IN IRRIGATED LANDS - REVIEW AND ANALYSIS OF CURRENT APPROACHES

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In arid conditions, land drainage has for primarily role to evacuate salts brought by irrigation water. The drainage criteria traditionally used in humid temperate climates are based on the water table level control and are no more relevant: the drainage design must be based on water volume to be subsurface drained, which has to match the required leaching fraction. To adequately calculate this volume one need to consider with accuracy the action of evapotranspiration on drainage functioning.

This paper reviews and analyses the main assumptions introduced in drainage equations which intend to take the evaporation into account. An original equation, based on the Boussinesq's equation, is proposed. This equation illustrates the action of the evaporation on the relationship between drainage discharge and water table level. It also demonstrates that the classical Hooghoudt's equation does not adequately describe this relationship in that case and thus the subsurface drained volumes.

A PHYSICALLY-BASED MODEL FOR WATER AND SALT TRANSPORT WITHIN IRRIGATION BAYS

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In irrigation areas where the watertable is both saline and shallow, salt accumulation in the plant root zone, and salt export into local river systems, are serious management problems. Determining the management arrangements which maximise plant productivity, but minimise the amounts of salt exported, requires a predictive modelling approach. Three mechanisms operate to transport salt into farm drainage and ultimately the river system, these are; wash-off of surface precipitated salt, exfiltration of groundwater, and direct groundwater seepage. However, these processes are part of a hydrologic system. In this paper, a model is presented which solves the hydrologic system operating within an irrigation bay. This water movement explanation is coupled to relations for salt transport. The model results are shown to agree well with observations of groundwater, overland flow, and salt transport obtained from a field experiment. The flow processes are explained using Darcy-Dupuit equation for groundwater movement, Richards equation for capillary rise, and the advection-dispersion equation for salt movement. Infiltration can be explained using a range of different empirical equations. A quasi-analytical Laplace transform based procedure is used to solve the governing system of coupled partial differential equations.

FERTIGATION IN CLOSED, RECIRCULATING CROPPING SYSTEMS IN GLASSHOUSE HORTICULTURE: SALINITY CONTROL

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Fertigation, i.e. irrigation using a nutrient solution, is a technique widely applied in closed, recirculating cropping systems in glasshouse horticulture. Closed, recirculating cropping systems are systems consisting of thin layers of a substrate with an impermeable bottom in which the excess of water plus dissolved nutrients are collected. This drainage water can be reused. Nutrients accumulate in the root zone, since 1) the uptake concentration is less than the concentration of the nutrient solution, and 2) at the surface nutrients are left behind when water evaporates. Excess amounts of solutions are added to prevent accumulation. The less this excess the more economic it is for the grower (less storage, less sterilization). What is an optimal fertigation strategy in such a system? With the help of a two-dimensional simulation model for describing water movement and solute transport, optimal fertigation scenario's can be derived with respect to salinity control. In this paper I will use such a model for some case studies.

AQUIFER SALINIZATION RISK ASSESSMENT IN SEMI-ARID ZONES

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Progressive salt accumulation constitutes a serious problem for sustainable farming in irrigated semi-arid areas. It is usually associated with poor irrigation water quality and the presence of a shallow water table, resulting in high evapotranspiration rates. In this study, the impact of irrigated practices on groundwater quality in shallow alluvial aquifers under semi-arid conditions has been investigated. A lumped unsaturated flow and salt balance model has been developed and coupled to a three dimensional saturated flow and transport model, PARADIGM, in order to investigate dissolved salt dynamics in shallow aquifers. The lumped model for the unsaturated zone applies a quasi-steady state approach to describe either recharge or capillary flow taking place in the vadose zone of the domain. The lumped model has been tested using both data from the literature and by comparison to results from a detailed unsaturated flow and transport model. The coupled model is computationally efficient and can be applied to stochastic analysis of salt transport using a Monte Carlo approach. The model is applied here to Rosario Farm, an alluvial domain in the semi-arid zone of Brazil, where groundwater is used for irrigation. This new integrated modelling approach enables an improved understanding of the impact of land use patterns and cropping schedules on the long term soil and groundwater salinity in Rosario Farm.

STOCHASTIC ANALYSIS OF SALT TRANSPORT IN IRRIGATED FIELD SOILS IN THE PRESENCE OF A WATER TABLE: A CASE STUDY IN NORTHEAST BRAZIL

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Texture and organic matter information from an irrigated site in the semi- arid region of Northeast Brazil has been used to establish the spatial behaviour of selected soil- water properties of major importance to salt transport, through pedotransfer functions. The inferred geostatistical model has been used together with climate data and other relevant information to assess the salt hazard to crops in a selected plot during irrigation periods, through Monte Carlo analysis with a numerical model for water flow and solute transport simulation including plant water uptake (WAVE).The study area has been modelled as a series of soil columns, with different soil- water properties. Realistic boundary conditions have been considered for the soil columns, with rainfall, evaporation from soil and plants, and irrigation taking place at the top, and with given prescribed water table fluctuations at the bottom. The influence of assumed parameters and conditions has been assessed through sensitivity tests on the stochastic outputs, for different parts of the growing season.

PEDOTRANSFER FUNCTIONS AND GEOSTATISTICS TO CHARACTERISE THE SPATIAL VARIABILITY OF SOIL WATER PROPERTIES IN SALT AFFECTED SOILS

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Consideration of soil hydraulic properties as stochastic processes for modelling heterogeneous field soils has been advocated over the last 20 years to replace traditional deterministic approaches. The fact that the spatial pattern of the soil water properties is not completely disordered has created an increasing interest in geostatistical techniques for describing soil variability. This study focuses on the analysis of variation and spatial structure of selected soil water properties and is aimed at the modelling of salt accumulation and transport in the unsaturated soil of an irrigated area in the Brazilian Northeast. The assessment of the soil water properties at the site has been centred on the use of alternative techniques to a large number of costly and demanding field and laboratory measurements. Pedotransfer functions, based on texture and organic matter data, have been used for the calculation of some soil hydraulic properties. Theoretical models have been fitted to the observed variograms. The validity of the models has been tested and a model has been selected.

PHYSICAL AND CHEMICAL PHENOMENA IN NATURAL WATER FLOW THROUGH MAGNETIC FIELD

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Natural water used for irrigation presents an open nonstationary heterogeneous multicomponent system closely connected with atmosphere. One should consider such water as gas-liquid solutions where there is a water-gas-solid inclusions equilibrium. While there is a certain relationship between the hydrodynamic regime and the magnetic field, magnetohydrodynamic forces are induced at the interphase boundaries of solid-liquid and liquid-gas when the same water passes magnetic apparatuses. Thelatter causes smallscale turbulization of the flow near microparticles and gas bubbles. Phenomena of dehydratation and generation of vortex in the proximity of icroparticles promote increasing the number of microcrystals of calcium carbonate in water volume, shift of the carbon dioxide equilibrium, increase of concentration of the molecular-dissolved CO_2 . Magnetohydrodynamic phenomena in liquid can result irreversible changes of the velocity of such heterogeneous processes as coagulation, crystallization, gas emission and etc. Application of the magnetic devices permits a controlled change of physical and chemical parameters of natural water for modification of filterability and dissolving capacity which may improve salt removal from saline soils and enhance moisture supply of plants and nutrit availability. Magnetohydrodynamic activation of natural water can find application in agriculture for leaching alkaline saline soil and irrigation.

SOIL SODICITY AS RESULT OF TEMPORARY SALINITY

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Soil sodicity is a severe case of human induced soil degradation that is related to the predominance of Na over divalent cations in both soil solution and adsorption complex. It adversely affects soil structure mainly for finer textured soils. This results in poor soil physical characteristics.
We emphasize situations in which relatively dry growing periods are followed by wet periods during which the arable land lies fallow. To control salinity, the salt concentration which has increased during the growing period is usually reduced by either additional irrigition at the end of the growing season or the temporal excess of rain water.
Consequently the salinity as well as the sodicity of soil changes. It will be shown by means of a conceptual model that along with salinity sodicity increases during the growing period. Upon flushing of salts after harvest, the sodicity will decrease, but not to its original value at the beginning of the growing period. Hence, this results in a net increase of soil sodicity. It will also be shown that although the increase during one year is small, for a longer period of time the sodicity will increase to high values. Therefore, sodicity control as well as salinity control are both prerequisites for sustainable land-use.

SALT EXPORT IN SHALLOW WATER TABLE IRRIGATED AREAS

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Hundreds of millions of dollars in farm production losses occur each year in Australia because of soil salinization but most methods for control rely on unproven methods. In northern Victoria, agricultural lands, mostly used for pasture, have been severely suffering from salinization over the last decades. Clearing of native vegetation and flood irrigation have reduced water table depths from around 10m in the 1900's to 0.6-1.2m today in the Barr Creek area. Thus, highly saline groundwater can reach the soil surface and contaminate plants. Salinity management in the future demand an understanding of water and salt export under various conditions corresponding to management options. A modelling approach is proposed to estimate water and salt balance at the irrigation bay scale (1 ha). Particular attention is paid to capillary rise and exfiltration processes. The model, using mainly analytical solutions, is simple enough to be used at the agricultural catchment scale with parameters provided by a Geographical Information System. Simulation results are compared with data measured in an instrumented irrigation bay.

HS4 Coupling fluid flow and rock stress models for fractured rock systems

Convener: Lunn, R.
Co-Convener: Hicks, T.W.

SOME SPECIALITIES OF FLUID FLOW IN FRACTURED-POROUS RESERVOIRS

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Some investigations (bouth mathematical modeling and field expeeriments) had been made upon the subject. Dinamic caracteristics of the reservoir received by bouth methods are very mutch alike each ather. The caracteristics are PRC (pressure restoring curve) and CTF (complex transmitting function).
To get well correlation could become possible by addition of relaxation constants into the model. So that Barrenblatt-Worren-Rutte model is just the special case of tqhe last.
Now it is possible to determine the coefficient of hydroconductivity of fractured sistems and time-dimention constant of porous bloks.
Exsperimental estimation of cycling procedure influence upon water content in oil well production had been made.

NUMERICAL MODELLING OF FLUID FLOW IN DEFORMABLE ROCK - ELASTO-PLASTIC MEDIA

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A number of geotechnically as well as environmentally important problems requires the analysis of coupled fluid flow and deformation processes in soil and rock, such as underground disposal of hazardeous waste or construction of tunnels. The first part of the contribution is focussed on aspects of the numerical treatment of the underlying system of coupled equations of elasto-plasticity and hydromechanics. Thereby, the finite element method is used for discretization in space in combination with unconditionally stable time marching schemes. In the second part, the resulting algorithm is applied to a number of examples of geotechnical interest to demonstrate the importance of those coupling effects. In particular, the simulation of stress-strain concentration near a tunnel, the analysis of local and global instabilities (shear bands, fluid saturated slope), the consolidation process, and the influence of forced groundwater flow on the stress distribution (supporting walls) are investigated.

Hydro-mechanical behavior of fractured rock mass

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Mehdi GHOREYCHI G.3S-Ecole Polytechnique
Olivier DIDRY EDF-GDF

To model large volume of rocks around underground facilities, a homogeneization method was proposed to determine mechanical properties of fractured rockmass. This methode allows to study development of anisotropy of permeability under the effect of anisotropic stresses. It also enables to quantify the role of state of stress on hydraulic properties at a large scale.The homogeneization method is based on mechanical and hydraulic REV determination. Beyond REV, fracture field is numerically simulated according to in situ observations. A finite element code allows to model the behavior of rock matrix and that of fracture. By applying differents loadings, the overall machanical behavior is identified. The aperture of each crack is given by mechanical equilibrium. Moreever, overall tensor of permeability is calculated with respect to different directions of mechanical loading.

TECTONIC CONTROLS ON FAULT HYDROGEOLOGY

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The hydrogeological role of faults and fracture clusters is a principal cause of uncertainty in the movement of fluid around a deep radioactive waste repository. In order to predict the rate of migration of radionuclides through a disposal system, it is important to understand the structure of the fluid flow paths of these features. This includes the need to consider the evolution of fault hydrogeology as a consequence of fault reactivation. Fault zones exist at a wide range of scales, and tend to have highly irregular structures, resulting in heterogeneous and anisotropic hydraulic conductivity. Changes in stress and fluid pressure (resulting from, for example, glacial loading and unloading), can lead to fault reactivation, and changes in fault hydrogeology. This paper presents the initial findings of a project on models of fault hydrogeology which is supported by the European Commission. The project involves the application of two models, FRACAS, which models fluid flow and transport in an interconnected fracture network and FLAC, which allows the structure of localized deformation zones to be represented and can be used to simulate pressure reduction within active fault zones.

COUPLED 3-D SIMULATIONS OF FORCED FLUID FLOW THROUGH FRACTURED, HOT ROCK

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For securing future energy supply by renewable resources geothermal Hot-Dry-Rock (HDR) systems are of great interest. World-wide, hydraulic experiments are performed on several HDR test site. Scenarios of the long term behaviour of HDR reservoirs can only be evaluated by numerical simulations. In the framework of a co-operation with the European HDR Project at Soultz (France), the code FRACTure is used to simulate the coupled response of a fractured media to forced fluid flow. A full finite element solution can be applied to the hydraulic, thermal and elastic processes. Several coupling mechanisms such as non-linear stress dependent joint aperture laws or linear elastic effects of temperature and pore pressure perturbations on the stress field developing in the bulk rock are treated. Thermal transport by conduction and advection is included in the fracture and the matrix.
In order to better understand the relevant processes for the long term behaviour a 3-D model with a restricted number of active fracture was setup. Such models allow to predict future HDR performance. They especially highlight the importance of the thermo-elastic mechanisms in modifying system behaviour over time. Comparisons to 2-D calculations are also given. This analysis is directed towards optimising the operation parameters of a HDR pilot plant.

COUPLING OF THERMOSEDIMENTARY CONVECTION AND HYDROELASTICITY IN POROUS MEDIA.

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Numerical simulations offer a possibility to investigate geophysical phenomena, which neither field observations nor experiments in the laboratory can record. We model the coupled thermosolutal-sedimentary and hydraulic-mechanical behaviour of flow processes in porous media. First, investigations of thermo-diffusive-sedimentary convection in porous media are presented. A numerical approach for the description of an additional sedimentary current of a dissolved particle species in porous media is given. The numerical investigations have shown that the additional settlement of crystals can cause instability in double-diffusive convective systems, where without sedimentation no convection occurs. Secondly, the fundamentals of the theory of consolidation and thermoelasticity are recast into the theory of thermohydroelasticity. Thermal effects on elastic material are described by an additional thermoelastic dissipation rate term. The integration of energy, fluid-flow and mechanical processes into one model leads to specific nonlinear response of the coupled system.

A NUMERICAL MODEL OF FLUID FLOW AND THE HYDRO-MECHANICAL BEHAVIOUR OF FRACTURED ROCK

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This paper discusses the development and application of FRACSIM-3D, a numerical model of fluid flow and heat transfer in fracture media, which couples changes in fluid pressure and rock stress with changes in fracture aperture. The model has been developed for use in assessments of hot dry rock geothermal energy reservoirs in Europe and Japan, but has potential applications in the analysis of fractured oil reservoirs and in radioactive waste disposal system performance assessments. Fractures are represented in FRACSIM-3D using random fractal distributions, which can be generated directly from borehole data. Several wellbores can be located in the modelling domain. Hydraulic stimulations at high fluid injection pressures and fluid flow through the fractured rock mass can be simulated. Fracture apertures respond to both the fluid pressure and the stress field by compliance. Heat extraction from the rock mass can be calculated and the thermal history at production boreholes recorded. A program for simulating tracer transport through a fractured medium has also been incorporated into FRACSIM-3D.

THERMAL FRACTURING IN HOT DRY ROCK RESERVOIRS

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The potential impact of thermally-induced fracturing during the circulation of a hot dry rock (HDR) geothermal reservoir is not well understood. Of particular concern is the potential for a short circuit for fluid flow to develop within the reservoir fracture system between the water injection and production wellbores. This paper assesses such effects through the construction of a reservoir model using the thermal-hydro-mechanical code HOTGRID. Model parameters are based on the European HDR reservoir at Soultz in France, and the fracture network includes an initial dominant flowpath through the reservoir. A range of thermal contraction rates (depending on water injection rate and temperature) have been simulated. At a low thermal contraction rate, the thermally-induced stresses spread out from the major flowpath and consequently no single flow path undergoes significant hydraulic enhancement. At a high thermal contraction rate, the induced thermal stresses are concentrated near the injection wellbore. As a result, the major flowpath does not become significantly more hydraulically enhanced than other flowpaths within the reservoir.

STRESS-PERMEABILITY EFFECTS IN THE BORROWDALE VOLCANIC GROUP, SELLAFIELD, UK

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This research forms part of Task 1 of the EC Programme DECOVALEX II 'to investigate the coupled hydromechanical effects on the Borrowdale Volcanic Group (BVG)'. The BVG is the host rock proposed by Nirex UK Ltd. for a deep radioactive waste repository at Sellafield in Cumbria UK. The research also forms part of a larger programme of work for the UK Environment Agency to assess potential hazard from the long term disposal of radioactive waste in the deep fractured rock formations of the BVG.

A statistically significant relationship has been identified here for the BVG between the effective stress field and the field permeability estimates. This relationship is incorporated into numerical modelling of the local fractured groundwater flow. The new model has been applied to simulate a constant drawdown test (performed by Nirex in 1995) and provides improved head distribution predictions.

DIRECTED POROUS FLOW IN RESPONSE TO TIDAL DEFORMATION

E. Millich
H.J. Neugebauer

A new driving mechanism for fluid flow in porous media is given by the combination of tidal forces and pressure dependent permeability. Two-dimensional computer simulations based on Biot's equations are able to reproduce the oscillating fluid flow in aquifers caused by tidal forces.

By using a constant permeability in the model the resulting flow disappears, if the velocity field is averaged over one tidal period. Using a permeability dependent on the effective pressure leads to a directed resulting flow averaged over one tidal period. In this case significant transport of heat and matter by the fluid flow is able over long periods of time.

Variation of the permeability shows a resonance behaviour of the resulting flow. The resonance permeability is proportional to the frequency of the tidal force and to the square of the spatial extension of the model.

Computer simulations for a 5 x 5 km extended region of modeling using realistic porous parameters yield to flow velocities in the range of mm/a.

HS5.1/SE24 Estimation of transport parameters in unsaturated soils

Convener: Haverkamp, R.
Co-Convener: Durner, W.

IN-SITU ESTIMATION OF UNSATURATED SOIL HYDRAULIC PROPERTIES AND SPATIAL VARIABILITY

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Tension disk infiltrometers have been used to investigate the statistical distributions of both hydraulic conductivity and capillary sorptivity in different hydrologic experiment programs (EFEDA (Spain), HAPEX/Sahel (Niger), and BOREAS (Canada)). The appropriate measurement strategy for soil water status and soil hydraulic properties in conjunction with regional experiments must recognize length scales and account for spatial variability of the soil processes and soil water conditions. Infiltration measurements provide a convenient tool for analyzing soil physical processes, complementary to short periods of the intensive measurements. Parameter estimations are obtained by using transient flow analysis of water infiltration. Significant attention has been paid to the fact that variations in soil properties are not necessarily random in space. This spatial structure may be taken into account in the data treatment by means of geostatistical concepts. Semivariogram analysis reinforces the need to consider partial correlation in ıodels. Results (BOREAS experiment) suggest that hydraulic conductivity and ›rptivity are best described by lognormal distributions.

TORTUOSITY COEFFICIENTS FOR STRUCTURED SOILS

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Estimates of the tortuosity coefficient in transport models are often based on pore-size distributions, porosity, and relative phase saturation and calibrated using measured data of the relative effective diffusivity. Tortuosity models for variably-saturated porous media assume a unique relationship between relative saturation, porosity, and diffusion path length. For estimating tortuosity coefficients in structured soils, both the pore structure and the relative saturation can be different for the soil matrix and the fracture pore system. Here, we propose a tortuosity model for use in dual-porosity transport models and evaluate the analogy between tortuosity in diffusion- and permeability-models in order to transform transport parameters. A comparison of different tortuosity models with experimental data for different soils suggests that the proposed dual-porosity tortuosity model represents experimental diffusion data for structured soils better than conventional tortuosity-models for aggregated soils. For estimating the dual-porosity tortuosity coefficient, the volume proportion, porosities, phase saturations, and the slope of the water retention function for both pore systems are required. Diffusion and hydraulic conductivity data obtained from the same samples, however, show that tortuosity factors as defined in solute diffusion models are not simply comparable with tortuosity factors used in permeability models, although they are of the same form.

TRANSPORT PROPERTIES OF POROUS CRACKED ANISOTROPIC MEDIA

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Methods for calculation of transport properties of porous cracked anisotropic media are developed. Various functions of cracks distribution over aspect ratio and angular orientation are considered. Tensor components of electrical (heat) conductivity and permeability are obtained. Comparison between elastic characteristics and permeability allows estimation of the permeability value.

POSSIBILITIES OF MAGNETIC RESONANCE IMAGING TECHNIQUES TO STUDY PREFERENTIAL FLOW IN NATURAL SOILS

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For saturated porous media, the MR signal is dominated by relaxation at solid phase surfaces it means it is sensitive to the pore-size distribution. The relaxation rate in homogeneous region of porous material is proportional to the surface/volume ratio of the pore space. For soils the surface relaxation can often be very fast due to mineralogical heterogeneity from pore to pore. The largest inhomogeneities occur at the boundaries between liquid and solid, where the magnetic susceptibility of the material changes most significantly. Due to magnetic susceptibility contrast between grain material and pore fluid, the secondary unravelable magnetic field gradients can be created with unwanted deterioration of the image. In a consequence, the majority of soils which are in their nature heterogeneous are very difficult to be as thoroughly characterised as synthetic samples or pure materials. For natural porous rocks, both T_1 and T_2 relaxation times were found as characterised by multiexponential decays, the distribution of relaxation times being linearly related to the pore-size distribution. For fractured rocks it seems reliable that the preferential flow in larger pores where the effect of grain - pore interface is less, will be measured quantitatively in very near future (Derbyshire et al, 1994, Chen et al.1995). The data for dual porosity models could be developed then. To be able to gain this information also for soils, further improvements of hardware and measurement protocols have to take place.

Determining the hydraulic properties of a swelling soil by parameter estimation

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Most of the methods currently used to determine the hydraulic properties of swelling soils (i.e., the shrinkage curve, the moisture retention curve and the hydraulic conductivity curve) tend to be time-consuming because they require measurements of several different parameters (either in separate experiments or by using very expensive equipment). We propose a simple evaporation experiment to simultaneously determine all three soil hydraulic properties. We illustrate the use of the method with samples of a vertisol from the Senegal River valley. The shrinkage curve, $e(\vartheta)$, is determined during the experiment by horizontal and vertical linear deformation measurements, while an inverse parameter estimation method is used to determine the retention curve, $h(\vartheta)$, and the hydraulic conductivity curve, $K(\vartheta)$. This inverse method relies on a water flow model which takes into account the three-dimensional and anisotropic deformation of the soil. In order to assess the reliability of the estimated parameter values, we compared the results with those obtained by a multistep outflow experiment. A good agreement was found between the results of the different procedures. Then, the sensitivity of the method to the deformation was analyzed. In the soil investigated, the inverse method does not seem to require the use of a water flow model that takes into account deformation. However, a correction for deformation is needed if the characteristic functions are sought in terms of the volumetric water content.

SORPTIVITY MEASUREMENTS OF CLAY SOIL AGGREGATES UNDER DIFFERENT WATER CONTENTS

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Characterization of the relationship between initial water content and aggregate sorptivity is helpful in modelling infiltration and transport in cracking clay soils. Therefore, a recently proposed sorptivity measurement technique for dry peds has been extended to various initial water contents. Experimental results for soil profiles from sites in Italy and the Netherlands have been compared with a commonly used sorptivity approximation based on soil hydraulic functions. The approximation gave realistic estimations for the sorptivity of some, but not for all of the investigated horizons. Therefore, the easy and rapid measurement technique used here can be helpful in order to obtain realistic values for clay ped sorptivity as a parameter of a physically based infiltration model.

IDENTIFICATION OF NONLINEAR SORPTION ISOTHERMS BY SOIL COLUMN BREAKTHROUGH EXPERIMENTS

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We consider the dispersive-advective transport of dissolved chemicals which undergo possibly nonlinear equilibrium and nonequilibrium sorption to the soil. The sorption mechanism is described by kinetic rate functions which are usually modelled by kinetic rate coefficients and sorption isotherms. These are to be identified by soil column breakthrough experiments.
It is crucial to set up experiments that lead to unique identifications of the unknown isotherms. It is shown that this condition is satisfied by outflow measurements which are obtained in soil column breakthrough experiments and that the minimum of an appropriate output least squares functional solves the identification problem.
A numerical scheme that is based on the output least squares method has been developed and implemented. The gradient that occurs in each optimization step can be efficiently computed by solving the discrete adjoint problem. The application of a parametrization which incorporates a multi-scale concept substantially accelerates and stabilizes the optimization process. Experimental and numerical results are presented.

WATER RETENTION CHARACTERISTICS AND PARTICLE-SIZE DISTRIBUTIONS OF FINNISH FOREST SOILS

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Some relationships exist between soil texture and the unsaturated soil hydraulic properties albeit no general relationship has yet been identified. Andersson's (1990) model with a mathematical sturucture was used to describe the water retention and cumulative particle- size distributions of Finnish forest soils. Andersson's model was compared with van Genuchten-like models. Profiles (54) for the data were taken from coniferous stands. In each profile samples (216) were taken from four horizons in order to determine water contents at pF-values 0, 1, 1.5, 1.8, 2, 3 and 4.2 and particle-size analyses.

IDENTIFICATION OF SOIL PARAMETERS USING INVERSE METHOD

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When dealing with large scale soil water transfer problems using aggregation of the Richards' equation, the traditional estimation of the required soil parameters cannot be applied for the hydraulic soil hydraulic characterization over the whole area. Thus, we focus this work on the parameter estimation from measurements of cumulative infiltration (an easily accessible integral property for which analytical expressions exists) by solving the inverse problem which consists of finding parameters that yield an infiltration profile optimally close to the measurements. While parameters like K_s and S_+ are easily identified, the shape parameter β, having a much smaller effect on the infiltration curve, is generally more troublesome. Experiments were performed with the initial conductivity set equal to zero, since the algorithm was unable to identify this parameter. But further investigations justify this behavior, suggesting that initial conductivity is defined by the 3 parameters already identified. The results thus imply that cumulative infiltration is uniquely defined by only 3 parameters and that the developed method, with a slight reformulation of the problem, clearly is able to identify these.

TRACER TRANSPORT EXPERIMENTS IN A GLASS-BEAD POROUS MEDIUM FOR ESTIMATING THE DEPENDENCE OF DISPERSION COEFFICIENT ON WATER SATURATION

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Changes in salt concentration with time were measured inside the uniform unsaturated glass beads column of length 100 cm and diameter 20.6 cm, that was leached at steady infiltration rates with solution of sodium chloride. Water content was measured at three depth using TDR-probes. By using different infiltration rates various moisture contents were available. Salt concentration was measured at two depths in three points of each cross section using platinum probes. Observed salt distributions were used to determine the dispersion coefficient. Analysis of experimental results allowed to recognize the mechanism of transport phenomena in porous media and gave some ideas concerning the measurement method. The dispersivity was found to increase with decreasing water content, from 0.065 cm for saturated medium to 0.75 cm for water content of 0.19 cm^3cm^{-3}, and to 1.5 cm for water content of 0.1 cm^3cm^{-3}. The breakthrough curves showed that the increase of solute mixing, with the decrease of water content, was caused by growth of flow velocities fluctuations for different path ways. It was pointed out in the paper, that the measurement of tracer concentration in one point gave local information about the solute transport in unknown path way. It is necessary to determine the mean concentration for the Representative Elementary Area.

ASSESSING TIME INVARIANCE OF PREFERENTIAL FLOW IN SMALL SOIL COLUMNS

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Displacement studies on bromide leaching under unsaturated steady state water flow conditions were conducted in two consecutive tests in 24 undisturbed soil columns (5.7 cm in diameter and 10 cm long) collected at a uniform grid from a loamy sand soil. There was large variability in the shapes of breakthrough curves (BTCs) of different columns during both tests including appearance of preferential flow features like early breakthrough and increased tailing in some columns. In principle, the preferential and non- preferential shapes of individual BTCs were maintained in two tests despite variations in water fluxes, flow velocities, pulse size and test durations. The field-average concentrations, computed as the arithmetic mean of individual columns, displayed double peak behaviour during both tests to reflect the effect of preferential flow. Transport parameters (retardation factor, R, and dispersion coefficients, D), of BTCs of both tests were highly correlated when all columns were considered; no definite correlation, however, existed amongst parameters of preferential and non- preferential flow columns considered separately. The consistency and time invariance of overall results of two tests suggest that the preferential flow features might be an strong intrinsic property of the soil under consideration which could be detected even in small columns.

LAECHING OUT OF A LARGE LYSIMETER — COMPARISON OF RETENTIVITY FUNCTIONS

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The soil water characteristic curve (SWCC), which is the relation between water content θ and soil suction h, masters the hydraulic properties of the porous medium soil. Because of capillarity it is related to the pore size distribution (PSD) and determines the unsaturated conductivity.
Lots of functions are proposed to fit as few parameters of $h(\theta)$ to measured points of the SWCC as necessary for accuracy and flexibility. Among these the function by VAN GENUCHTEN, and its refinement by FREDLUND are analyzed with respect to parameter sensitivity and impact on the derived conductivity functions. Furthermore a doubled VAN GENUCHTEN function is tried, in order to represent the incedence of macropores by a bimodal PSD.
The feasibility for environmental modelling of these approaches is compared by simulating daily leaching out of a lysimeter. The grass covered lysimeter at St. Arnold, North-West Germany, has a surface area of 400 m^2. It is filled with a podsolic soil and drained at 3.50 m depth. SWCC measurements have been performed at 8 suctions of soil samples from 5 different depths. The simulation model ARNOLDL bases on the Richards equation and the Penman evapotranspiration with empirical crop coefficients. Adapting the SWCC to the soil sample measurements, the model is calibrated by fitting the saturated conductivity to agreement of modelled and measured leaching data.

CALIBRATION OF A DUAL-POROSITY MODEL USING SOIL COLUMN AND FIELD DATA

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Dual-porosity models are designed to simulate preferential solute transport through structured soils. Problems with the application of mechanistic dual-porosity models arise from the independent determination of the large number of model parameters that are required. In this study, we consider water flow and non-reactive tracer transport in undisturbed soil columns as well as in an 0.5 ha agricultural catchment. The parameters of the flow model are independently evaluated by fitting dual retention and conductivity functions simultaneously to data of standard soil hydraulic measurements. The dispersion length for solute transport in the matrix pore system is obtained by steady-state soil column experiments. Mass transfer parameters, such as the characteristic half-width and the geometry of the matrix are estimated from soil profile observations. The hydraulic conductivity and the effective diffusion coefficient at the matrix/fracture interface, are calibrated by fitting simulation results for water movement and solute transport to measurement data obtained by soil column and field tracer experiments.

Spatial Variability of Soil Water and Nitrate of the Ground Moraine in Northeast Germany

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The Ground Moraine of Northeast Germany is characterized by small scaled spatial structures. The research was aimed at studying the structures and the effects of varying relief conditions and soil physical properties on soil water dynamics and nitrogen supply.
On various relief-positions the nitrogen status was researched at different times. The water potential, soil moisture and regularly soil hydraulic functions were determined. Field measurements were used to calculate the waterbudget components. The results show high differences in the ETI (mm/d) in one field. They are caused by the soil and relief conditions. In simulations with a two dimensional water model, the slope and exposition for three typical soils were considered. It could be shown that the seepage varies up to 20% within one soil unit. Long term simulations of the actual evapotranspiration and seepage show ranging seepages in the field from 54 up to 100 mm/a for the whole area. Histograms and the normal distributions of mineralic N pools for the sampling-time show a high variability: The CV ranges from 38 to 69 %. The CV varies in single positions in the average from 36 to 47%. The nitrate supply at the bottom is generally higher than at other slope positions.The influence of the relief can even be found by analyzing datasets with geostatistical methods. Empirical semi-variograms in show ranges of 10 m for the nitrate-pool and a typical "hole-effect". The morphological structures result in specific nitrate-pools in the same field.

CONE PENETRATION TEST METHOD FOR K(h) DETERMINATION

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Effective clean up of contaminated sites requires characterization of impacted soils. In many cases this includes unsaturated soils. The hydraulic conductivity of unsaturated soil, K(h), is important for remedial design and accurate prediction of the movement of water-borne contaminants to ground water. A modified cone penetrometer has been designed for measuring K(h) in situ. The advantage of this tool is that it does not produce soil cuttings and it may be applied up to 30 m below ground surface. The device injects water into the subsurface while tensiometer rings measure increasing pore water pressures in the soil. Flow data are logged continuously with a computer. The data from short tests (5 - 10 min) are analyzed to obtain the van Genuchten parameters for K(h) using parameter estimation. The Levenberg-Marquardt optimization method is used to minimize an objective function expressing the differences between measured and numerically-predicted flow responses. HYDRUS-2D, a variably saturated flow code, is used to predict the cumulative inflow volume and pressure increases for inclusion in the objective function. Inversions of field-scale laboratory test results are shown and compared to independently-measured parameters. These results suggest that the saturated hydraulic conductivity, K_s, may be found using this method. Refinement of the analysis is necessary to obtain the other parameters of interest. Implications for further development of this method are discussed.

TWO-DOMAIN ESTIMATION OF WATER FLOW IN MACROPORE SOIL

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A nuclear tracer technique is a promising tool for detailed investigation of water flow and solute transport in the unsaturated zone of soil. After infiltration and redistribution of the nuclear tracer solution, well detectable infiltration front in the soil matrix is formed. Additional infiltration of the non-tagged water results in a displacement of that front which is dependent upon the hydraulic properties of both macropore and matrix domains. Considering, for the sake of simplicity, a soil without macropores and the piston flow in it, the cumulative infiltration I results in the displacement I/n_{ef} of the front, where $n_{ef} = \Theta_s - \Theta_r$ is the effective porosity, Θ_s is the saturated water content, and Θ_r is the residual water content of that soil. In a soil with two-domain flow the same cumulative infiltration I results in an infiltration front displacement $h < I/n_{ef}$ in the matrix domain. In this case, $I = I_m + I_h$, where $I_m = I - h(n_{ef} - n_m)$ is the cumulative infiltration into macropores, $I_h = h(n_{ef} - n_m)$ is the cumulative infiltration into matrix, and n_m is the macroporosity. In this way, an estimation of macropore flow in the clay loam soil ($n_{ef} - n_m \approx 0.3$) was made, utilizing the results of the 1993-96 tracer experiments performed at the Experimental Station of the Research Institute of Irrigation in Most. The macropore flow was of about 49 % of the total flow in the barley field in the 1993 experiment, 19 % in the maize field in the 1995 experiment, and 55 % in the no-tilled soil covered with grass in the 1996 experiment. It can be seen that the warm and rainless second half of April 1993 resulted in nearly as high macropore flow in the barley field as that in the no-tilled soil.

AUTOMATIZED INSTRUMENTATION FOR WATER FLOW AND SOLUTE TRANSPORT OBSERVATION BY THROUGH-THE-WALL TECHNIQUE

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In the through-the-wall measurement technique, a radioactive tracer is monitored without any disturbance as it flows past the dry-access observation well. Two types of measurements can be obtained: concentration distribution over time at the preselected elevation, and concentration distribution over depth. The measured concentration may be viewed as the flow-weighted concentration [Moltyaner, 1987]. The automatized instrumentation, built up by the ECO-Electronics, makes both types of in situ measurements possible during small-scale solute transport experiments in which an investigated solute is replaced by the gamma-emitting tracer with similar physico-chemical properties. The measurements are rapid, non destructive, able to locate heterogeneities in field soils, and do not influence solute transport. Due to very small dose and short halflife of the tracer, they are not harmful to the environment.

CRACKED SOILS IN THE NOPEX AREA : THE INFLUENCE OF THE SOIL CRACKS ON THE INFILTRATION PROCESS

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Flat NOPEX area in its lover part is covered by a heavy clayey soils with cracks forming during the dry part of the vegetation period.It was recognized, that soil cracks can substantionally intensify the infiltration process. Soil cracks formation was studied at two agricultural sites (Lovsta and Marsta of the NOPEX area, near Uppsala, Sweden). The following soil characteristics were estimated at both sites: 1) relations between cracks porosity P_c and soil water content w, (P_c = f(w)), 2) specific cracks area on a soil surface A_c, and 3) length of cracks circumference on a soil surface L_c . Using the above mentioned soil cracks characteristics, the specific volume of cracks V_c (volume of cracks related to one square meter of soil surface) as a function of depth below the soil surface z was estimated, as well as the specific cracks surface S_c . Volume of cracks V_c (z) is an additional volume for precipitations accumulation, while cracks surface S_c(z) - when filled-can increase the infiltration surface. The estimated specific total volumes of cracks were V_{c1} = 3.6 cm , V_{c2} = 2.7 cm at Lovsta site on May 30,1994, (CFE1) for soil covered by rye canopy. Aditional infiltration surfaces of cracks were S_{c1} = 5.9 m^2 and S_{c2} = 4.8 m^2. It means that, under given circumstances, the soil cracks can contain water layer of 36 and 27 mm and infiltration surface can be increased by up to 5,9 and / or 4.8 times, depending on depth of the filled part of soil cracks.

INVERSE MODELLING TECHNIQUES FOR DETERMINING HYDRAULIC PROPERTIES OF POROUS MEDIA BY TRANSIENT OUTFLOW METHODS

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A series of multistep outflow experiments were carried out to identify the unsaturated hydraulic properties of two homogeneous porous media (glass beads and sand). As it was pointed out by Kool and Parker (1987) long soil columns were used to achieve the desired resolution of the parameter identification problem. Because of the sharp fronts of water content decrease during these experiments the hydraulic functions are assumed to be represented by the complete van Genuchten - Mualem closed-form expressions with variable coefficients α, n, m and θ_r. The values of θ_s and K_s were measured directly. The inverse modelling technique consists of two steps: computation of the response surfaces as initial estimation and a optimization of the parameters using a numerical model and the Levenberg-Marquardt-scheme. A sensitivity analysis with respect to α, n and m shows, that conditions of local identifiability are satisfied if exclusively the measurements of water content in the column are considered. Additionally the cumulative outflow is necessary to check the mass balance of the numerical simulation. For both porous media good estimations can be achieved and the resulting hydraulic functions were used to verify the model with respect to other drainage experiments.

IMAGING FLUID FLOW IN UNDISTURBED SOIL USING ELECTRICAL RESISTIVITY TOMOG RAPHY

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Soil structure has a significant impact on fluid flow. There is thus a need for non destructive measurements which provide spatial information of properties as soil moisture storage, solute concentration and flow velocities. Electrical Resistivity Tomography (ERT) provides the spatial distribution of internal bulk electrical resistivities in a vessel given measurements of the transfer resistances between electrodes on the circumference of the vessel. Using non-linear inverse method a 3-dimensional image of the electrical resistivity distribution is obtained. By applying a suitable electrolytic tracer to soils the change in bulk electrical resistivity can be interpreted as a change in the fluid conductivity. Images can be developed as a series of time slices thus revealing the pathways of the tracer as it moves through the soil core. This then allows some determination of solute breakthrough curves at many voxels within the soil core. Such results are presented here from a solute tracer study under steady state unsaturated flow. We observed that different soils responded differently depending on the internal structure.

DIELECTRIC CHARACTERIZATION OF BENTONITE AS A FUNCTION OF FREQUENCY, TEMPERATURE AND VOLUMETRIC WATER CONTENT

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We report laboratory measurements of the complex valued relative permittivity $\epsilon_r = \epsilon_r' - j\epsilon_r''$ of montmorillonitic bentonite of hydrothermal origin from volcanic rocks from the *Serrata de Nijar* in the *Cabo de Gata* area (Almería, Spain). The data are parameterized by frequency f, temperature T and volumetric water content θ_{vol}. The geophysical characterization of potential candidates for nuclear waste disposal requires, amongst other quantities, the precise knowledge of the spatial distribution of the volumetric water content in a bentonite barrier surrounding a waste container. Such information can be obtained by exploiting the strong correlation between the relative permittivity of bentonite and its volumetric water content. In reality temperature T also varies and therefore we must consider this quantity as a parameter in the laboratory measurements. If in the field experiment time domain methods are used then it is important to remember that a TDR signal is a mixture of frequencies and therefore the frequency dependence of ϵ_r must also be known *a priori*.

DISCRETE MULTIPHASE FLOW SIMULATION IN POROUS MEDIA

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The interpretation and modelling of multiphase flow and retention properties of porous media must take into account the complexity of the internal geometry of the microscopic channels. Unsaturated flow in subsurface hydrology is a specific case of multiphase flow in porous media. It is the case when the porous space of a soil is filled by water and air, which are the two fluid phases the most usually present in the natural environment. Displacement simulations in realistic pore networks (2D/3D) are presented for cases where capillarity controls fluid motion and spatial distributions. With discrete geometry tools, the real network is reduced to an integer radius map called "background distance map". A local transform allows a flow path "skeleton" to be extracted. In equilibrium conditions, a set of radii, connected to the injection (or drainage) boundaries, are detected in this topologic representation. The skeleton inverse transform is then applied to determine the flow geometry. Complex displacement sequences, involving partial or total imbibition and drainage, can be simulated that way. Resulting equilibrium fluid distributions are used to estimate transport properties for each phase. The corresponding algorithm allows studying the irreducible wetting phase saturation or fractured media.

DISCONTINUOS PHENOMENA IN SOIL WATER FLOW

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Within the scope of a hydrological program launched in 1983 in the Šumava Mts., the soil water regime is measured by water tensiometers in correlation with the rainfall and evapotranspiration data. In certain periods, the soil water regime could be explained only by assuming an irregularly oscillating outflow of soil water into lower horizons. In these situations a big volume of water flows through the soil; therefore, on the hydrological scale, this phenomenon forms a great part of the outflow from a watershed. In order to deeper elucidate the soil water movement, some nuclear tracer experiments in the Šumava Mts. - the mean elevation 800 m a. s. l. (Czech Republic) and in the Danubian Lowland - the mean elevation 100 m a. s. l. (Slovakia) were arranged. The main purpose of our experiments was to reproduce the phenomena observed in situ under controlled conditions: 1. to stabilize water sprayed over the soil surface in the soil profile, 2. to loosen stabilized water, to generate outflow oscillations. The main conclusion is that the soil water movement is essentially nonhomogeneous and instable.

PARAMETER ESTIMATION OF UNSATURATED SOIL HYDRAULIC FUNCTIONS FROM EVAPORATION EXPERIMENTS

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A laboratory inverse method is developed for determining soil water retention and hydraulic conductivity functions simultaneously from an evaporation experiment using a parameter estimation technique. The unknown parameters in closed-form analytical expressions employed for describing soil hydraulic properties are estimated by a non-linear least-squares optimization problem which minimizes the deviations between the numerical solution of the transient flow process and the real system response measured during the evaporation experiment. Different analytical relations are used in this study to describe soil hydraulic properties. The transient water flow in soil is simulated by numerically solving the Richards equation with the appropriate initial and boundary conditions. The reliability of the proposed method is shown for different types of soils by comparing the estimated soil hydraulic properties with data points obtained via the instantaneous profile method, and by analyzing the effects of data error on parameter estimates. Additionally, parameter sensitivity analysis and computation of response surfaces address questions relating to problems of identifiability and uniqueness of the inverse solution.

ANALYSIS OF SOIL WATER RETENTION SPATIAL VARIABILITY USING PEDO-TRANSFER FUNCTIONS

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The objective of this study was to evaluate some published pedo-transfer functions (PTFs) in the light of their ability to quantify the spatial structure and variability of soil water retention adequately. Measured data for testing were obtained from undisturbed soil samples taken from the uppermost layer of different soils along a 5-km transect with constant spacing of 50 m. Each sample was subjected to standard laboratory analyses to determine soil physical and chemical properties, whereas a sand-kaolin box and a membrane plate apparatus were used to measure soil water retention data points. For each sample, the retention data were fitted with van Genuchten's analytical relation. Dependence of fitted and PTF-estimated water retention characteristics on separation distance along the transect was examined using geostatistics and experimental semivariograms were described by a combination of pure nugget and spherical models. Overall, statistical analyses indicate that summary statistics and sample distributions of the PTF-estimated retention characteristics are very close to those of the fitted variables used as reference for comparison. Although the quality of kriged interpolations based on soil property data obtained by simplified methodologies still gives cause for concern, results show that the structure of spatial variability exhibited by the considered variables along the study transect is described well enough when using PTFs for determining soil water retention characteristics.

Water content profile estimation in porous media from spatial deconvolution of TDR waveforms measurements

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Until now the Time-Domain Reflectometry (TDR) technique has been mostly used to determine bulk water content of porous materials from the analysis of the transit time required for a microwave pulse to travel on a known length of transmission line. In this work, we propose a method of spatial deconvolution of TDR signals that will allow the direct estimation of water content profiles. This method is based upon the theory of reflection of electromagnetic waves in the case of inhomogeneously filled waveguides. An expression of the reflection coefficient was obtained based on the concept of distributed parameters using a circuit-analysis approach. The frequency domain analysis of TDR waveforms is used to link the data measurements with the theory. Preliminary results have been obtained for discontinuous profiles using glassbeads and demineralized water. This technique has since been applied directly in the field for soil-moisture profile determination. Part of this work was supported by a student grant from the CAPES Brazilian Finance Agency.

DETERMINATION OF HYDRAULIC PROPERTIES OF SOIL SAMPLES BY TRANSIENT FLOW EXPERIMENTS -DYNAMIC EFFECTS AND TIME SCALE DEPENDENCY

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Inverse modeling of transient inflow/outflow experiments has become a widely used method to determine the hydraulic properties of undisturbed soil samples in a fast, accurate, and efficient manner. In the past there has been some concern on whether hydraulic properties of soils are of static and time-invariant nature, and thus independent of the imposed boundary conditions. We performed experiments where we imposed smooth changes in water pressure to the bottom end of undisturbed samples of a sandy soil. The observed cumulative outflow and backflow, as well as tensiometric potentials and water contents at two depths in the soil samples were continuously recorded and used in an inverse modeling procedure for the optimization of the hydraulic functions. By repeating the experiment with a varying speed of the pressure changes, the outflow and backflow process was forced to take place at different time scales. Our results indicate that transient water flow in undisturbed soil columns is not in accordance with the classical one-phase flow theory, as expressed by Richards equation with time-invariant retention and conductivity characteristics.

ESTIMATING UNSATURATED SOIL HYDRAULIC PROPERTIES FROM MULTIPLE TENSION DISC INFILTROMETER DATA

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In a previous study we showed that infiltration curves measured with a tension disc infiltrometer at one particular tension do not provide enough information to estimate van Genuchten's soil-hydraulic parameters by numerical inversion of the Richards equation for unsaturated flow. In this paper we analyze the use of infiltration curves obtained with the tension disc infiltrometer at several consecutive tensions to estimate soil hydraulic parameters. We also investigate if parameter identification can be improved by adding easily obtainable information, such as the final water content below the permeameter, or by using Wooding's [1968] analytical solution in combination with numerical inversion of the Richards equation. The study was carried out in the field using a disc permeameter with radius of 10 cm and consecutively applied tensions of -20, -10, and -3 cm. The average initial water content of the soil beneath the disc was 0.077 and the final water content below the disc was about 0.25, i.e., 0.12 lower than the saturated water content measured in the laboratory. Our parameter estimation procedure combined the Levenberg-Marquardt nonlinear parameter optimization method with the numerical model HYDRUS-2D for solving the variably-saturated flow equation. The soil hydraulic parameters obtained from the field disc permeameter experiments will be compared with retention data measured in the laboratory.

USER-FRIENDLY INTERFACE FOR HYDRUS-1D CODE IN WINDOWS ENVIRONMENT

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An interactive graphics-based software package HYDRUS-1D which was developed in support of the computer model HYDRUS 6.0, will be presented. HYDRUS-1D may be used to simulate one-dimensional variably-saturated water flow, heat transport, and movement of solutes involved in first-order decay reactions. HYDRUS uses the Richards equation for simulating variably-saturated flow and the Fickian-based convection-dispersion equation for both heat and solute transport. The water flow equation incorporates a sink term to account for water uptake by plant roots. Hysteresis in the soil hydraulic properties is accounted for by the model. The solute transport equations consider convective-dispersivetransport in the liquid phase, as well as diffusion in the gaseous phase. The transport equations also include provisions for nonlinear nonequilibrium reactions between the solid and liquid phases, linear equilibrium reactions between the liquid and gaseous phases, zero-order production, and first-order degradation reactions. HYDRUS was coupled with the Levenberg-Marquardt nonlinear parameter optimization method to estimate van Genuchten's soil hydraulic and solute transport parameters from transient water flow and solute transport experiments. The user interface includes data pre-processing and graphical presentation of the output results in a Microsoft Windows environments.

MEASUREMENT AND INTERPRETATION OF SATURATED HYDRAULIC CONDUCTIVITY IN THE FIELD CONDITIONS.

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The measured saturated hydarulic conductivity of soils without macropores represents conductivities of soil matrix only. These values are useful for modelling of the soil water transport by mathematical models, which are based on the Richard's equation. However, saturated hydraulic conductivity measured in the field conditions, with a developed system of macropores, reflects more conductivity of the macropores. Both saturated hydarulic conductivities can differ and it is important to separate them. Presented contribution deals with values of the saturated hydraulic conductivity measured by Guelph permeameter (K_{GP}) and with values of the hydraulic conductivity measured by disc permeameter (K_{DP}) in the near saturated state (h_w = -1.7 cm). All measurements were made in 1 cubic meter of soil in 5 verticals and in 3 horizons. Each value K_{GP} and K_{DP} was measured in the same vertical direction. First, K_{GP} was measured in horizon z_1 = 30cm and then K_{DP} was measured in the same horizon (in the near saturated state). Then the same measurements were repeated in horizons z_2 = 70 cm and z_3 = 95 cm. The average rations K_{GP} / K_{DP} were: 10.9 in horizon 30 cm, 3.0 in horizont 70 cm, and 1.4 in horizont 95 cm.

UNCERTAINTIES IN EXPERIMENTAL ESTIMATION OF HYDRAULIC PROPERTIES IN UNSATURATED HETEROGENEOUS SOIL

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Two different methods were used for determination of the hydraulic conductivity function and the soil water retention curve to find out the differences in measured θ(h) and K(h) and its propagation to the predicted K(h). The disk tension infiltrometer and the evaporation method were applied, in both methods, soil water pressure head was measured simultaneously. The undisturbed soil samples of coarse sandy loam were taken in Korkusova Hut (Czech Republic). This highly heterogeneous soil type (Cambisol) exhibits the preferential flow and the dependence of the saturated hydraulic conductivity on the initial soil water content. The unsaturated range near water saturation was of the main concern. From measured data the parameters of van Genuchten's analytical closed form expressions of retention curve were evaluated. Unsaturated hydraulic conductivities were calculated from water flux densities and hydraulic gradients. Average of upward water flux density was estimated from changes of water content in time. High sensitivity of unsaturated hydraulic conductivity values on negligible changes of hydraulic gradient leads to uncertainty in the soil hydraulic function determination. Results obtained for each of 6 soil samples are similar. The high degree of hysteresis is indicated in most of the cases. The study was performed in laboratories of ZALF in frame of joint cooperation.

SLOPING LYSIMETER RAINFALL-RUN-OFF EXPERIMENTS ON LOAMY SOILS

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Heterogeneity complicates the determination of water transport properties in soils at different spatial scales. In addition, different boundary conditions may affect the flow domains participating to the water transport process. Therefore there is a need to develop experimental devices which enable to characterize flow properties at different temporal and spatial scales.

Within this study, an experimental device was developed to measure functional soil water balance terms (drainage, soil water storage and run-off) at the scale of a small plot subjected to variable boundary conditions. The experimental device consisted of a high quality indoor rainfall simulator and a 6m^2 indoor sloping lysimeter. The lysimeter has a depth of 0.5 m. Functional balance terms such as soil water storage, soil water run-off , and drainage were measured for fourty unsteady state flow experiments. The experimental data were analyzed to quantify the effect of antecedent soil moisture and slope on total run-off. Future research envisage to combine physical rainfall-run-off and infiltration models with inverse modelling procedures to characterize the unsaturated flow properties at the scale of the plot subjected to different rainfall events.

EFFECTS OF SOIL TYPE AND WATER FLUX ON SOLUTE TRANSPORT

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Solute concentrations were monitored at six different depths using TDR in 1-m long 0.8-m i.d. lysimeters during breakthrough experiments. The lysimeters contained undisturbed soil monoliths taken from three different soil types: Plaggept, Hapludalf and Glossudalf. To investigate the effect of the water flux on the solute transport, the breakthrough experiments were repeated for two flow rates: 0.01 m/d and 0.005 m/d. Since solute concentrations were measured at several depths in the soil profile, the validity of two distinct solute transport processes to describe lysimeter-scale solute transport was investigated: (i) the stochastic-convective transport process (CLT model) assuming no mixing of solutes, and (ii) the convective-dispersive transport process (CDE model) assuming complete mixing of solutes. Solute transport in the Plaggept and Hapludalf soils was better described by the CLT model whereas the CDE model was more suited for the Glossudalf soil. Solute dispersion or solute transport heterogeneity was larger for the Plaggept and Hapludalf soils than for the Glossudalf soil. The parameters of the transport models depended largely on the applied water flow. In addition, the solute transport heterogeneity increased with increasing flow rate, especially in the Hapludalf soil. This was probably due to the activation of macropores for the higher flow rate.

MAGNETIC RESONANCE PROPERTIES OF WATER IN SOILS WITH VARYING SOIL WATER CONTENT AND VARIOUS COMPACTION

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A study of bulk NMR parameters (the longitudinal (T_1) and the transverse (T_2) relaxation times and the proton density (Mo)) of water in soils as obtained by 4 basic MRI protocols was conducted. The pulse sequences: single 90° pulse giving Mo(FID), single Spin Echo sequence with TE=2.9 ms giving Mo(SE), CPMG sequence giving T_2 and Mo(T_2) and Inversion Recovery sequence giving T_1 and Mo(T_1) were used. Two representative soils were chosen from both ends of the range of soil suitability for MRI: "good" fine sand (Hupselse Beek, Netherlands) and "bad" coarse sandy loam (Korkusova Hut, Czech Republic). For each soil 1 undisturbed and 4 disturbed samples of various bulk densities were examined. Each sample was scanned in 3-6 steps of different water content covering the whole range from the residual moisture to the saturation. Stretched exponential and 3 component exponential functions were used to fit the T_1 and T_2 relaxation. The fraction of amount of water visualized using each of MR methods was derived from the ratio of the acquired signal intensity (Mo) and the signal intensity produced by the equal amount of water, the part of the defined solution of D_2O+H_2O+$CuSO_4$. For all methods used, a relationship of NMR parameters to the water content and porosity is evident, the fine sand showing significantly clearer trends. Variations of Mo values determined by different MR methods are caused by very fast decay of the signal in soils and by the timing of pulse sequences in the research instrument used.

EFFECT OF WATER CONTENT, SALINITY, SURFACE CONDUCTANCE, AND ION-MOBILITY ON ELECTRICAL CONDUCTION IN UNSATURATED SANDY SOILS

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Solute transport parameters of laboratory soil columns and field soils are more and more derived from experiments involving the measurement of the bulk-soil electrical-conductivity, σ_a (Sm^{-1}). Models that decribe σ_a as a function of soil-water conductivity, σ_w (S m^{-1}), water content, θ (m^{3}m^{-3}), and other soil parameters are used to obtain the total concentration of the soil solution. Samples of three sandy soils with different CEC (low/intermediate/ high) were saturated with a NaCl-solution with salinities in the range of 0.01-1.0 Sm^{-1}. In addition, samples of the soil with intermediate CEC were saturated with a $CaCl_2$- and $(C_2H_5)_4NCl$-solution. Simultaneous measurements of the hysteric water-retention-curve and σ_a (with TDR) on all these samples were made. The aims of this study are (1) to test several models of σ_a as a function of θ, σ_w, CEC, and ion-mobility and (2) to study the effect of hysteresis on electrical conductivity in sandy soils.

COMPARISON BETWEEN THE INSTANTANEOUS PROFIL METHOD AND THE MULTISTEP OUTFLOW METHOD FOR MEASURING THE UNSATURATED HYDRAULIC CONDUCTIVITY OF SOILS UNDER LABORATORY CONDITIONS

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There is still a need for cheap, rapid but accurate methods for measuring the unsaturated hydraulic conductivity of soils as input for water and solute transport models and for obtaining its spatial variability. The multistep outflow method using pressure chambers and inverse modelling technique is a cheap and rapid method for determining the unsaturated hydraulic conductivity. In this study the multistep outflow method is compared to the instantaneous profile method using tensiometers and TDR probes. Soil cores were taken from a chernosem soil near Vienna (Austria) at different locations and 3 depths. The results of the two methods are in good agreement except for the samples in 60 cm depth where soil inhomogeneity might have a strong influence on the hydraulic properties. Additionally at three core samples both methods were applied simultaneously. Two of them showed similar hydraulic conductivity functions. The saturated hydraulic conductivity obtained as a fitting parameter of the multistep outflow method is not an accurate estimate compared to the field saturated hydraulic conductivity measured with the guelph permeameter method.

RELATIONS BETWEEN HYDRAULIC SOIL CHARACTERISTIC PARAMETERS.

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To describe water content transfer, in the unsaturated zone of soils, knowledge of the soil hydraulic properties is required. Different functional relationships can be chosen for the description of : a) the relation between volumetric water content (θ) and the soil water pressure (h) and b) the relation between volumetric water content (θ) and hydraulic conductivity (K). These relations have to obey constraints imposed by the use of the transfer equations such as Richard's equation. In a compilation of data concerning several hundreds of soil, including particle size distribution, h-(θ) and K-(θ), a parameter study is carried out to establish physically meaningfull relationships between soil properties (texture) and the transfer models Since the soils in the database cover a wide range of soil types, taken mostly from the literature, it is possible to identify relevant shape parameters.
Results suggest that some relations between the shape parameters of the functional relationship of the hydraulic soil properties exist, and these relationships depend on the chosen functional.
The present soil catalogue will be available for interested researchers in this study.

SOIL POROUS MEDIUM STRUCTURE, UNSATURATED SOIL HYDRAULIC PROPERTIES AND WATER FLOW MODELS

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The current interest of hydrology subsurface transport process modeling in the soil porous medium structure (SPMS) arises from the need to predict the model parameters in connection with static and dynamic of physicochemical soil state in function of soil solid phase and SPMS properties. This is especially the case of the unsaturated soil hydraulic properties relating the water flow (WF) models with simulated real process. Proposed approach is based in the identification one of elaborated SPMS models ("*textural*", "*structural*", "*aggregated*", "*swelling*", "*alkali*", "*gypso-calcareous*") forming a hierarchical system using the indicator soil parameters. These models describe the SPMS explicitly in the terms of specific volume of interconnected and subordinated subspaces of transport and dead-end pores. For each of these SPMS models WF model is associated applying the modified Richard's equation for transport pore subspaces and equilibrium equation between blocked air and compressing it water in dead-end pore subspace. The water retention curve of all subspaces is estimated from the SPMS properties and fitted by multi-Veibul's function. To predict the hydraulic conductivity of transport pore subspaces the Mualem's and Burdine's models are adapted. This approach to estimate the unsaturated soil hydraulic properties using the SPMS models was validated by laboratory and field experimental data of various soils of Bulgaria, Hungary, Uzbekiston, Russia, France and Switzerland.

HS5 Flow and transport in unsaturated soils

02 Modelling the effect of heterogeneity of soil properties on flow and transport

Convener: van der Zee, S.

AN ENERGY BALANCE MODEL FOR EVAPORATION, MOISTURE, AND TEMPERATURE OF A BARE SOIL

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A one dimensional model simulates soil surface temperature and soil evaporation. The procedure is based on the equations for heat flow at the soil surface and includes vapour diffusion and a semi-empirical correction function for the surface vapour pressure. The effects of changes in three important model parameters, governing the surface moisture and temperature conditions, were studied. One parameter studied governs the vapour pressure correction as a dynamic process. The second parameter is the vapour diffusion tortuosity factor and the third is a minimum hydraulic conductivity, that prevents water flow rates from beeing extremely low during dry conditions. Measurements of soil water content and soil temperature in a bare sandy loam were used to evaluate the models behaviour. Vapour pressure at the soil surface was found to be substantially lower than saturated vapour pressure at topsoil moisture potentials as high as -100 hPa. Correction of the surface vapour pressure proved to be necessary to restrict too high evaporation losses from the soil. Results based on measured temperatures indicated enhanced vapour diffusion and a probable value of the diffusion tortuosity coefficient close to 1.0, whereas a value close to 0.7 was more likely according to the soil water contents and calculated evaporation.

STOCHASTIC MODELING OF SOLUTE TRANSPORT IN VARIABLY SATURATED POROUS MEDIA WITH RANDOM RECHARGE

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Approximate analytic solutions were developed to predict the transport of inert solutes in variably-saturated randomly heterogeneous porous media subject to a random rainfall boundary condition. Travel time pdfs to a series of vadose zone control planes were derived using the rainfall probability density function, mean soil properties, and control plane depth. The mean and variance of the solute flux past the control planes were then determined using the derived travel time statistics and an advective-dispersive impulse response function for the soil system. Results obtained agree with Monte Carlo simulations conducted using random rain sequences and spatially correlated random hydraulic conductivity and moisture release properties in a numerical solution of the Richards equation and the advection-dispersion equation. Both methods show that the mean water flux does not depend on depth whereas its variance decreases asymptotically with depth. The mean travel time and variance both asymptotically increase linearly with depth. The peak of both the mean solute breakthrough and the break through standard deviation attenuates with travel distance as the plume spreads. For a constant mean infiltration flux, finer textured soil with higher mean water content experiences increased solute spreading, and thereby lower peaks in both the mean and the standard deviation of the solute breakthrough at a given control plane.

NON-ERGODIC TRANSPORT OF SOLUTES IN EVOLVING SCALE POROUS FORMATIONS

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Transport in heterogeneous formations characterized by the lack of a characteristic scale is studied analytically and numerically. We propose first-order exact solutions for the effective longitudinal coefficient of macrodispersion D_L, the expected value of the second order longitudinal plume moment $\langle S_{11} \rangle$ in a stationary increment random log-transmissivity field characterized by a power law semi-variogram $\gamma_Y = ar^{\beta}$, that slightly extend and support recent results. The analytical solutions are derived under the linear approximation of flow and transport. We propose also analytical solutions for the variance of S_{11} which is a measure of the interval of confidence of the estimate of the actual spreading provided by $\langle S_{11} \rangle$. In order to test the analytical solutions we relaxed the linearity hypothesis and solved numerically the fully non-linear problem. For $\beta < 1$ we observed a good agreement between analytical and numerical solutions. For $\beta > 1$, the analytical solution overpredicts the numerical one. The numerical solution for $\langle S_{11} \rangle$ still grows with a growing rate larger than 1 but less than the value predicted by the analytical solution.

ESTIMATION OF LANDSCAPES POLLUTION IN REGIONS OF ROCKETS STAGES FALL

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The areas on which separated parts of rockets fall occupy about 50 millions hectares in Russia. The separated stages of rocket contain significant amount of toxic rocket fuel which contaminate the area. In connection with the Russian conversion programs the main aim of our investigation was to estimate time period needed to decrease fuel pollution of soils to the safety level so that these areas could be used for human activity again. The space-distributed physically based model of river basins ECOMAG was used for modelling of migration and transformation of rocket fuel in landscapes of rockets stages fall regions. The hydrological submodel of ECOMAG describes the main processes of hydrological cycle of land. The geochemical submodel describes the transfer processes of rocket fuel in the soil and aquatic transport taking into account interaction with soil matrix, biochemical degradation of rocket fuel. For the collection, analysis and preparation of initial spatial data GIS technique is used. The model calculations showed that the time period during which the levels of fuel pollution decrease to the maximum permitted concentration runs from 5 to 20 years depending on type of soil, intensity of hydrological processes (which are connected with heterogeneity of soil properties) and initial pollution. Field measures on the rockets separated parts fall areas were carried out and information about temporal changes of fuel concentration in soils, groundwater zone and river waters was collected. Our model estimations agree with the results of field investigations.

APPLICATION OF GEOSTATISTICS TO SITE CHARACTERIZATION

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The accuracy of a numerical program can be improved when it is calibrated for a specified site. Site characterization, selection of important soil parameters, measurement of these parameters, and design of a hydrological monitoring program are elements used in field calibration. The focus of this study was to find methods to measure and describe saturated hydraulic conductivity, K_s at a 1.40-ha vegetated site in Aiken, SC, known as the Bamboo field. Site characterization was conducted at a depth of 20-cm throughout the site. The tests were performed at locations along a regular grid. Two field methods; double ring and Guelph permeameter were used to measure K_{fs}. In addition, undisturbed samples were collected for laboratory testing. In the laboratory, falling head and constant head tests were used to measure K_s. Descriptive statistics were applied to results from four different measurement methods. Over 70 test locations were evaluated where all four techniques were employed. Results from all methods showed a highly skewed data set which did not conform to a normal distribution or log-normal distribution. In addition, the data showed preferential clustering. The four methods were then studied to determine spatial continuity in the field. Sample variograms of different lag distances were evaluated to determine the degree of spatial continuity which may exist on the site. Due to the data distribution, other variograms were evaluated. The covariance variogram was found to be the most robust in description of spatial continuity. Ordinary kriging was used to estimate K_s at locations throughout the site.

HETEROGENEITY STRATUM PIEZOMETRIA BY FILTRATIONAL WAVES OF PRESSURE METHOD

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The problem of spreading of filtrational waves of preasure (FWP) in relaxing system with heterogeneity like in-pieces and exponential forms in the zone around the well is solved by numerical method, in particular for exponential form is used Runge-Kutt method. Computer modelling shows it is maximum influence of section-line on spreading of FWP for in-pieces form stratum heterogeneity at 1/4 and 3/4 wave lengths'distance. Identification stratum parameters consists in ascertainment of heterogeneity form. relaxing model by using Newton's method. For ascertainment of parameters of zone around the well is recommended making of researches with 7-10 frequencies of FWP from 10^{-2} to 10^{-4} by using small perturbs with harmonic form.

HETEROGENEITY AND SENSITIVITY - SOME IMPLICATIONS FOR MEASURING AND MODELLING FLOW AND TRANSPORT

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The effect of heterogeneity of soil properties depends greatly on the sensitivity of soil processes, and the way they are modelled, to those properties. Different soil processes and model outputs vary in their sensitivity to soil properties. Furthermore, that sensitivity may change over time and from one scenario to another. This paper examines some implications of heterogeneity and sensitivity for measurements and modelling of soil processes at an effluent-irrigated plantation. Distinct changes in soil hydraulic properties have been measured across the 4 ha site. Despite these changes, measurements at 24 locations showed that the movement of a bromide pulse was reasonably uniform. A range of other scenarios, modelled using the different hydraulic property sets but uniform boundary conditions, showed variable effects on a number of flow and transport processes, including deep drainage, salt leaching, and soil water status.

A STOCHASTIC APPROACH FOR THE STUDY OF THE VARIABILITY OF SURFACE FLUXES OF A SAVANNAH (HAPEX-SAHEL) IN RESPONSE TO THE VARIABILITY OF SURFACE PROPERTIES

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A data set of 18 days, including 3 rainfall events (78 mm) was gathered on a savannah. The SiSPAT SVAT model was calibrated on this data set. A stochastic approach was used to study the sensitivity of surface fluxes to the variability of the parameters of the surface soil hydrodynamic properties, the leaf area index and the minimum stomatal resistance. The field was divided into 10 independent soil profiles, where fluxes were assumed vertical. Equiprobabilistic values of the parameters were drawn from appropriate statistical distributions and statistics of the outputs calculated. Runoff and bare soil evaporation were found to be mostly sensitive to soil properties. Transpiration responds more to LAI although the vegatation is sparse. Maximum variations of ±20% for the components of evapotranspiration were found and more than ±100% for runoff. The high sensitivity of the model (based on the Richards equation) to the specification of soil properties show that such an approach must be used cautiously for long term studies if robust water budgets are wished. However, no significant bias is observed for ±50% variations of the parameters when only one 1-D run is performed with the median parameters, showing that aggregation of surface properties can be achieved in this case. The main problem is then the accurate estimation of those median parameters, given the sampling effort required.

A FIELD SCALE BROMIDE-TRACER EXPERIMENT ON A SANDY SOIL TO EVALUATE SPATIAL VARIABILITY OF LEACHING

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To evaluate leaching of non-reactive solutes on a field scale a bromide tracer experiment on a sandy soil in Northern Germany was conducted. The tracer was applied on a bare arable field plot (35 x 4 m) in autumn. The vertical displacement of the bromide under natural rainfall conditions was measured from autumn till spring (main period of nitrate leaching). With 60 suctions probes in three different depths local and field scale breakthrough curves and by soil coring up to a depth of 2.5 m at two different dates 50 solute concentrations profiles were measured. Determination of the transport parameters with a Convection-Dispersion model showed that the dispersivity increases almost linear with depth. Evaluating the variability of the local breakthrough curves and the bromide concentration profiles gives insight into the heterogeneity of leaching on a field scale and the uncertainty of the determination of nitrate leaching with suction probes.

MODELLING EFFECTS OF SOIL HETEROGENEITY AND BOUNDARY CONDITIONS UNCERTAINTY DURING UNSTEADY WATER FLOW

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A numerical model based on the first order Taylor expansion of the discretized Richards' equation is proposed. This model allows both to consider hydraulic characteristics of soil as random processes and boundary conditions as random variables. The uncertainty propagation on flux and pressure head distribution during wetting and drying processes is analyzed for different soil models. Behavior of flux toward water table is specifically investigated. Comparisons are provided between numerical model and Monte Carlo simulations results to evaluate limits of validity of the first-order approximation.

EFFECT OF MAIZE CANOPY ON MOISTURE PATTERNS IN DUTCH BLACK PLAGGEN SOILS

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Man-made raised sandy soils in the Netherlands are distinguished in "brown" and "black" plaggen soils. When dry, the brown soils are wettable, but the black ones are water repellent. Maize canopy induces remarkable wetting patterns in dry, black plaggen soils. During one growing season transects were sampled in maize cropped black plaggen soils at the experimental stations Heino and Cranendonck. Due to interception and stemflow, water was concentrated towards the roots of the maize. Between the maize rows, higher soil water contents were found too, caused by rainwater dripping to the ground from overhanging leaves. Microtopographical depressions further concentrated the dripped water. Redistribution of soil water from wet areas into dry areas is restricted because of the actual water repellency of the dry sand. As a consequence, the variation in soil moisture content is considerable. However, these irregular wetting patterns did not induce preferential flow; the dry, water repellent subsoil impeded and resisted infiltration into the deeper subsoil during several months.

LINEARLY ADSORBING AND FIRST ORDER DECAY REACTIVE SOLUTE TRANSPORT IN HETEROGENEOUS UNSATURATED POROUS MEDIA

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Average results of numerical Monte Carlo simulations of flow and reactive transport in vertical two dimensional unsaturated porous media are presented. Flow and dispersive transport equations are solved using finite elements method, while the convective transport is solved using particle tracking method.
First order decay (λ), hydraulic conductivity ($Y = \ln[K]$), water content (θ) and reactive partition coefficient (k_d) are assumed to be spatial random functions defined by their statistics and correlations.
We evaluated the effect of varying k_d and its degree of correlation with the saturated hydraulic conductivity on the plume spreading through the time dependence of the growth rate of the spatial moments. Variation of water content and first order decay is assessed separately.
Results will be compared to their counterpart analytical solutions for flow and transport of reactive and passive solute in saturated and unsaturated porous media.

CHARACTERIZATION OF HETEROGENEOUS DYE PATTERNS USING IMAGE ANALYSIS

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Flow patterns induced by small-scale heterogeneities can only be described adequately by a method resulting in a spatially high-resolved concentration distribution. In this study image analysis technique was used to analyse and describe flow patterns.
In a field experiment the dye tracer Brilliant Blue (C.I. 42090) was continuously applied as a line source to observe the lateral and longitudinal solute spreading. Six plots in total were irrigated under unsaturated conditions at two infiltration rates and three amounts of cumulative infiltration. Vertical profiles were excavated, prepared and photographed with diffuse day light.
The pictures were digitized on PhotoCD and preprocessed with a geometric correction, a correction for the inhomogeneous illumination and a color adjustment. Small soil samples were taken out of the stained plume for calibration purposes. The Brilliant Blue was extracted and analysed in the laboratory. The color values were determined at the corresponding locations in the image. This relationship between concentration and color values was used to determine the concentration in each pixel.
Within each treatment several profiles were photographed to analyse the spatial heterogeneity.

FUZZY SET APPROACH TO THE ASSESSMENT OF INFLUENCE OF CHEMICAL AND SOIL PROPERTIES IMPRECISIONS IN THE RESULTS OF SCREENING MODELS

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The results of a screening model are always approximate, lying within an imprecision range. In this contribution, we focus on the effects of imprecision in groundwater contamination parameters introduced either by subjective or state-of-the-art estimates of coefficients, or through spatial and temporal variability of measured parameters. A non-classical method, based on a fuzzy set approach to account for imprecision in chemical and soil parameters and ranges of results from potential pollution indices is proposed. In order to illustrate the methodology, emphasis is placed on the evaluation of imprecisions in potential groundwater contamination by pesticides using the Attenuation Factor index (AF). The results of this application demonstrate the suitability of the fuzzy set approach in evaluating imprecisions in screening models. The method furnishes both an imprecision range for the mean value of AF and adds a degree of confidence to this range.

PREDICTION UNCERTAINTY OF PLUME CHARACTERISTICS BEACAUSE OF LIMITED SAMPL ING POINTS

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The idea of this work was to assess how the sampling pattern affects the prediction uncertainty of plume characteristics. This has been studied by a simple modelling approach and by using a finite element simulation model for saturated and unsaturated transport (SUTRA). In the simplest case, a symmetrical or elliptical normal plume entered a system of regularly and randomly placed sampling points. The plume characteristics were studied by the method of spatial moments. The horizontal variance was approximately correctly predicted for the symmetrical normal plume when sampling points were placed regularly, but fluctuated in the case of an elliptic plume. The vertical variance fluctuated, both for the symmetrical and elliptic normal plumes, with extreme values coinciding with correctly predicted centres of mass. When sampling points were placed at random the prediction became even more uncertain. The SUTRA simulation with a homogeneous soil profile revealed the same kind of prediction uncertainty. The heterogeneous case, based on simulations with random fields of varying degree of heterogeneity, revealed less prominent fluctuation of variance, but gave systematically a lower variance than expected. When sampling points were placed at random fluctuations were completely smoothened out, but variances were still systematically lower than expected.

MODELING THE EFFECT OF CHEMICAL HETEROGENEITY ON SOLUTE LEACHING IN OXIDIZING PYRITIC MINE SPOILS

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Mine spoils originating from lignite-coal strip-mining operations in Lusatia in south-east Germany are highly heterogeneous with respect to physical as well as chemical soil properties. The overburden material contains iron-bearing sulphide minerals, e.g. pyrite, which - when oxidized - lead to soil acidification and produce acid mine drainage which serves as a long term source for groundwater contamination in the area. During mining operation, overburden material which has already been pre-oxidized and acidified to various degrees, is being dumped and incorporated into the spoil forming a heterogeneous pattern of more or less acid regions. To analyze the situation, solute transport in and leaching from a hypothetical vertical cross-section (40 x 50 m) is described using two-dimensional reactive multicomponent solute transport model including oxygen diffusion in the soil air and coupled with a kinetic-type pyrite oxidation model. Spatial distributions of hydraulic, transport, and chemical parameters and initial conditions in the cross-sectional area are randomly generated by kriging using estimated geostatitical parameters. Results of long-term simulations in which scenarios of different spatial distributions of initially acidified regions are compared can be used to improve long-term predictions of acid mine drainage and groundwater quality.

INFLUENCE OF SOIL PROPERTIES AND HYSTERESE ON CALCULATED FLUXES IN UNSATURATED PEAT PROFILES

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For the recolonization of Sphagnum mosses on cut-over bogs the growing conditions of Sphagnum mosses require must be met. Growing conditions for Sphagnum mosses are determined by the groundwater level and soil properties, variation of soil properties can therefore result in a variation of growing conditions.
In a cut-over bog, at locations with different vegetation, peat types and groundwater levels samples were taken for the determination of the physical soil properties. The methods used were the sand box and the evaporation method of Wind. The unsaturated conductivity between samples taken at one location and between different locations could variate considerable. Different groundwater levels have an effect on the unsaturated conductivity, at dry locations it was a factor of 10 lower as at wet locations. The vegetation had no influence on the physical soil properties.
The determination of the water retention - and absorption curves showed a strong hysterese effect.
The effect of variation of soil properties and hysterese on fluxes calculated with an one dimensional hydrological model (SWATTRE) will be shown. Physical soil properties of samples taken at a distance of only 20 cm can differ considerable and this results in different calculated fluxes. Therefore, for an ecological interpretation of the model outcome the variation of soil properties must be known.

RANDOM NETWORK THEORY AND CONDUCTIVITY OF SOILS WITH PREFERENTIAL FLOW PATHS

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Laboratory experiments with soil samples of different sand-clay mixtures revealed that the entire pore space within the soil was not invaded by the permeating fluid. In many instances, the flow was concentrated in an intricate network of preferential flow paths, that were formed as small particles (originally part of the soil matrix) eroded away from the pore walls. Dye experiments were used to characterize the network of preferential flow paths as a random network. Sections of the soil samples were scanned, and the data was analyzed to determine the distributional properties of the preferential flow paths in terms of their lengths, diameters, orientations, and connectivities. These statistics were used to develop a theoretical estimate of the hydraulic conductivity based on the average properties of the random network. These results were compared with a pipe network model of the preferential flow paths. The results bring out the important variables for estimating hydraulic conductivity, and also shed light on the representative elementary volume for such soils. Implications of these results on understanding and modeling of flow through such heterogeneous formations will be discussed.

SPATIAL VARIABILITY OF WATER AND BROMIDE TRANSPORT IN A SANDY LOAM OF THE GROUND MORAINE IN NORTHEAST GERMANY

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Firstly, this field study was aimed at analysing effects of varying soil horizon thickness and soil spatial variability on water flow, water balance and transport phenomena. Secondly, numerical simulation models were tested in view of ability to predict water transport and bromid leaching characteristics (see contribution of Hammel et al., 1997). On a 30 m transects soil moisture (TDR) and tensions were measured over a two years period versus time and depth. Besides, Lithiumbomide was spread out on the bare soil in autumn to observe transport characteristics. In spring, soil samples were taken up to 1.4 m depth in a grid of 20 to 10 cm to determine bromide distribution and mass balance. Retention curve and unsaturated hydraulic conductivity were determined from the diagnostic horizons using an instantaneous profile approach. Results of the field measurements show that actual evapotranspiraion varies up to ± 40 mm/a; variation of vertical seepage is still higher due to the occurance of stagnic B_t-horizons and sand wedges which lead to local interflow. In avarage, 75% of the applicated bromid was detected within 1.2 m depth with a maximum in 0.8 to 1.2 m depth. Though results of the bromide concentrations show a high spatial variability, no indications of bypass flow and preferential flow could be observed. Main factors that cause spatial variability are thickness of the diagnostic soil horizons, occurance of stagnic horizons, and the influence of sand wedges, which influence the horizontical water and solute transport up to a range of 2.3 m.

FIELD SCALE SOLUTE TRANSPORT IN A HETEROGENEOUS UNSATURATED SOIL: EXPERIMENT AND MODELING

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Transport of bromide in a layered unsaturated field soil is studied by a tracer experiment and independent numerical simulation. The measured concentration distribution showed typical phenomena such as horizontal redistribution and large field scale disperison and appeared to be related to the geometry of the soil horizons. For given boundary conditions, these features are determined by the variability of the water velocity field which is governed by the spatial heterogeneity of the soil hydraulic functions. It is assumed that the hydraulic functions are spatially heterogeneous at two scales, at the larger scale of the soil horizons and at a smaller scale within the soil horizons. For the simulation their spatial structure was derived from local measurements of the hydraulic functions and the geometry of the horizons.
The simulated tracer distribution exhibits surprising similarity with the measured bromide concentration. The simulation reproduces both, the early breakthrough of solute at specific locations and local concentration hot spots that have no clear correlation to horizon geometry.

IDENTIFYING EFFECTIVE FRACTURE CONTINUA FOR CONTAMINANT TRANSPORT IN HETEROGENEOUS MULTI-SCALE FRACTURED AQUIFERS

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Regional contaminant transport in fractured porous formations is often simulated with dual-porosity or dual-permeability models. In such models the heterogeneous formation is separated into two coupled continua, one representing the fracture network, one representing the porous or/and permeable rock matrix. Only little work has been done to define separated continua for aquifers with different fracture systems, each possessing unique properties. In the proposed paper we will present a study focusing on the identification of relevant aquifer parameters that should be incorporated in a general guideline for the determination of the number of fracture continua and the type of multi-continuum model that should be applied, respectively. Contaminant transport in discrete, stochastically generated fracture networks comprising a macro-fracture system and a micro-fracture system with variable properties was investigated applying a mixed Lagrangian-Eulerian solution scheme. A wide range of relative geometrical and physical parameters was considered and the relative fracture density and the relative apertures were identified as the crucial parameters for the systems behaviour as a single, dual-porosity or dual-permeability system in terms of the multi-continuum approach. Applying a multi-continuum finite element model it was demonstrated that the multi-continuum approach is capable of accurately simulating heterogeneous fracture systems.

DESCRIBING HETEROGENEOUS FLOW FIELDS USING SPATIAL DISTRIBUTION OF HYDRAULIC PROPERTIES

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We study the relationship between flow patterns observed in a small-scale field experiment (plot size 1 x 1 m) and the spatial distribution of the unsaturated hydraulic conductivities. The dye tracer Brilliant Blue was used to visualize the flow paths during a controlled irrigation experiment in an unsaturated field soil. The observed dye spreading patterns depended largely on the irrigation rate. Lateral dye displacement was more pronounced at the higher irrigation rate and the patterns were also much more irregularly shaped.
The aim of this study was to simulate the observed dye patterns describing the heterogeneity of the field soil based on the variability of the hydraulic conductivity function using scaling theory. The hydraulic properties were measured on small soil cores taken in the same field to determine the scaling factors. The hydraulic conductivity function was predicted from the water retention curve using a unsaturated hydraulic conductivity value as matching point. The matching points were measured with a steady-state flux controlling method. The heterogeneity of the water flow field in the simulations is characterized by the measured distribution of the scaling factor and its autocorrelation function. Simulated solute spreading was compared with the observed patterns.

ANALYSIS OF SOLUTE TRANSPORT IN UNSATURATED SOIL AT BET DAGAN SITE

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The Bet Dagan field experiment consists in spreading of one conservative and two reactive solutes over the soil surface and in their downward transport following irrigation and rainfall. The water content and the concentrations of all three solutes are measured by taking 20 samples at four times and at five depths at each time. The analysis of the measured data is carried out by developing a mathematical model of flow and transport, based on column model. The soil is viewed as a set of homogeneous vertical columns whose saturated conductivity is regarded as a random function of the horizontal coordinate. In each column the flow and transport of the conservative solute are modeled by one dimensional equations with neglect of pore scale dispersion. The transport of reactive solutes accounts additionally for instantaneous equilibrium sorption and mass losses. Closed form expressions of the ensemble mean water content and of both conservative and reactive solute concentrations are derived. The properties of soil and transport parameters are identified by a best fit of the analytical solutions and of the measurements.

PROFILE BULBS AND FRONT FINGERS IN MOSTURE FLOWS AS A CONSEQUENCE OF HYSTERESIS

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Analysis of similar moisture profiles advancing in dry soils during the constant rate infiltration [1-3] is proposed. The known results for nonmonotonous form of these profiles both for 1-D regime and finger type flows are interpreted as a consequence of hysteresis of conductivity depending (k) on water content (θ). The estimations made supplement the idea [1] that stable fingers in soils exist due to pressure-moisture hysteresis. A self-similar solution of the Richards equation that propagates as a 'rigid' profile is developed. A bulb of the profile in 1-D case is caused by the following property: at sufficiently low moisture boundary wetting -- drying curves lay below strait lines passing through the origin of $k-\theta$ coordinate system. Persistent fingers for 2-D flows a studied for structural models of capillary bundles. The mean velocity of finger type flow can be higher than for the nonmonotonous profile which advances faster than the usual monotonous one.

INFLUENCE OF DISOLVED AND COLLOIDAL PHASE HUMIC SUBSTANCES ON THE TRANSPORT OF HYDROPHOBIC ORGANIC CONTAMINANTS IN SOILS.

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The fate of hydrophobic organic chemicals (HOC) in soils is predominantly determined by the interactions with soil organic matter. HOC-accumulation is found in soil horizons high in organic matter (O / A horizons). This is the consequence of hydrophobic interactions of HOC with the organic phase of natural soils and / or with soot, tar, or coal admixtures in contaminated soils. The controlling process is a partition between the soil matrix and the solution phase, where the partition equilibrium is dominated by the solid phase. Disolved and colloidal size organic matter (DOM) affects the partition equilibrium and leads to an increasei in the water solubility of HOC due to an association (sorption or solubilisation) between HOC and DOM. DOM is a reactive component of the soil solution with respect to the immobile solid phase. Therfore the overall mobility of HOC in soils is enhanced due to co-transport with DOM or reduced due to interactions of the carrier DOM with the solid phase (co-sorption). The presentation will focus on the specific processes relevant to the DOM-mediated fate of HOC in natural and contaminated soils. Special consideration will be given to the effect of (i) soil physico-chemical parameters (ionic strength, composition, pH), (ii) DOM of different origin, and (iii) aging of a contamination on HOC release.

A THREE-DIMENSIONAL REACTIVE CONTAMINANT TRANSPORT IN POROUS MEDIA

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The mathematical simulation of three-dimensional nonconservative solutes transport in porous media is presented as solving three-component transport problem with a sorption and complexation in saturated aquifer. This model is founded on a differentional equation system including ground water filtration, convection-dispersion, sorption and complexation equations with the account of mass action expression. An upstream weight balance finite element method is used for numerical realization of the model. The proposed technique eliminates the oscillations of a numerical solution when convection dominates the dispersion. The obtained linear equations systems are solved simultaneously by iterations. The numerical results of the three-dimensional reactive contaminant transport problem with sources and a pumping well for various kinetic constants are presented. A behavior of the concentrations is complex with the local maximums in some cases. In comparision with a two-dimensional case, there is a qualitative and quantitative great diffrence of the space concentrations distributions from the plane solutions.

GEOELECTRICAL IMPEDANCE TOMOGRAPHY AS A TOOL FOR DETERMINATION OF SPATIAL VARIABILITY OF SOIL PROPERTIES AT FIELD SCALE

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The determination of the spatial variation of soil physical properties is important to evaluate water and solute transport processes at field scale. Using a multi-electrode-array the apparent specific electrical resistivity of two differently textured soils in Northeast Germany was measured with several spatial resolutions. The resulting profile sections of the apparent electrical resistivity (down to 5 m soil depth) indicate zones of higher or lower resistivity within the observed transect of 100 m length. Additionally, soil texture, soil water content and the penetrometer resistance were determined. Zones of higher specific electrical resistivity correspond in the loamy clay soil with spatial patterns of sand distribution. Within the sandy soil zones of lower resistivity occurr corresponding to loamy patterns. The spatial pattern of the penetrometer resistance are similar to that of the electrical resistivity. The geoelectrical measurements seem to reflect zones of preferred water and solute transport.

NITROGEN LEACHING OF AN AGRICULTURAL SOIL WITH SEEPAGE

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The heterogeneity of water flow affects many processes governing the transport and transformation of nitrogen. Heterogeneity of soil properties and flow characteristics will be experimentally assessed in a 24 x 285 m section of an arable field with a permanent grass cover. This site is situated in a seepage area. For quantifying nitrogen leaching at parcel scale it is necessary to estimate the upward water and nitrogen flux. Measurements and simulations are performed to quantify the upward flow at the experimental site. Several groundwater tubes in two aquifers are used to measure differences in hydraulic heads. These measurements show that the seepage flux within the parcel is heterogeneous. Simulations are performed by the groundwater model Microfem for quantifying the amount of seepage and for determine the origin of the seepage. Nitrogen leaching is calculated based on nitrogen concentrations measured in groundwater tubes and based on concentrations measured in drains. These two methods of calculating nitrogen leaching are compared with each other. Results of one year of measurements and simulations are presented.

EVALUATION OF FIELD-SCALE BROMIDE MOVEMENT FROM TILE-DRAIN OUTFLOW AND SOIL COLUMN STUDIES

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Two methods have been used to derive field-scale bromide breakthrough curves (BTCs) at a tile-drained field site. The first method involved conducting bromide leaching tests under unsaturated flow conditions in 36 small undisturbed soil columns collected at a uniform grid of 15 m. Measured individual BTCs were assembled by computing arithmetic means across local measurements to represent field-scale solute behaviour. This area-averaged BTC followed a bimodal log-normal distribution. A calibrated bimodal log probability density function was applied to simulate bromide breakthrough at 1 m depth plane (depth of tile drains). The second method consisted of a field tracer experiment. Drain discharge and bromide concentrations were registered over a six month period to obtain a second field-scale concentration distribution. BTCs from both methods were characterised by the occurrence of an early first concentration apex at same amount of cumulative discharge. BTC from column method, however, had a second more dominant matrix peak which was not observed in the drain outflow.

DESCRIBING WATER FLOW IN MACROPOROUS FIELD SOIL USING MODIFIED MACRO MODEL APPROACH

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A simulation model to describe one-dimensional soil water flow in a macroporous field soil is developed and applied to the field soil at the Golzow and Arensdorf sites in Northeastern Germany. A two domain approach according to the MACRO model (Jarvis et al., 1991a, b) is used: Water flow in the matrix domain is described with Richards' equation; this is coupled with bypass flow in macropores calculated with kinematic wave theory. Special attention is given to the profile bottom located within the ground water zone. A sensitivity analysis and simulation results show that the model can well describe matric potential time series as well as ground water table fluctuations. At the Golzow site these fluctuations were small when rainfall intensity was small. On the other hand, bypass flow caused instantaneous ground water table rises after rainstorm events although the soil matrix was still unsaturated in this soil with macropores. At the Arensdorf site as well an impact of macropores has to be considered for modelling.

MODELING CONTAMINANT TRANSPORT WITH BIODEGRADATION IN HETEROGENEOUS GROU ND WATER AQUIFERS

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Numerical modeling of contaminant transport in ground water is a valuable tool to characterize the migration behavior of contaminant plumes experiencing complex f low patterns and complex chemical reaction processes. This modeling provides a cost effective means to design remediation strategies. In the present paper we present a Lagranian-scheme model based on the Particle Tracking Random Walk (PTRW) method, and apply the model to the simulation of contaminant transport in both homogeneous and heterogeneous flow domains. The model includes geochemical reaction processes such as solute adsorption, and biochemical reactions due to microbial digestion of contaminant substrate. Solute adsorption is modeled using a nonlinear Freundlich isotherm. The biodegradation process is modeled using a Monod model for bacterial growth and substrate digestion. The transport of bacteria is incorporated in the model with the same PTRW procedure used for the contaminant. Preliminary results obtained using a linear biodegradation model show an increase in contaminant degradation with increase in the rate of a dsorption. Simulations using the Monod model are currently under study and we intend to pre sent the results obtained for both homogeneous and heterogeneous flow domains.

INVESTIGATION OF THE BARRIER MECHANISM IN SANDS OF CONTRASTING TEXTURE

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Capillary barriers consisting of tilted fine-over-coarse sand layers are being investigated as landfill cover systems. Under unsaturated conditions the textural contrast delays the vertical drainage by capillary forces and the moisture that builds up above the interface will flow downdip until a critical saturation is reached. In order to estimate the relevant parameters and develop applicable design criteria experiments have been carried out at different scales: core samples, in a 8 m long flume and on 40 m long test sites. The experiments revealed, that vertical flow in the coarse layer occurrs along preferential paths ("fingering"). However, below a critical tension at the interface the fingers remain hydraulically inactive and the cover performs as an effective barrier. Although observed fingering in the coarse medium diverges from Darcian assumptions, numerical studies suggest that when the domain scale is large enough the flow regime of a capillary barrier (lateral and vertical discharge rates as well as the pressure distribution above the interface) can be predicted at an acceptable degree of precision.

SIMULATION OF EXPERIMENTAL GRAVITY-DRIVEN UNSTABLE FLOW IN WATER REPELLEN T SAND

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A laboratory experimental setup consisting of a vertical chamber (0.5mx0.5mx0.01 m) filled with a uniformly dense sand is used to assess the effect of soil repellency on water movement. A small percentage of sand grains are treated with a water re pellent substance. Water is applied at a low rate to the top of the packed sand, and water flow patterns in the chamber are measured with a light transmission method. Various experiments were run by c hanging the percentage of water repellent sand grains (ranging from 0% to 8%). It was observed that with the increase in percentage of water repellent grains (from 0%), the finger widt hs decreased upto a certain point beyond which the finger width increased. Main wetting and main d rainage water retention curves have been derived for the sand for the various percentages of water repellency. A mod el for simulating gravity-driven unstable flow will be applied to the simulation of the laboratory results. The model is based on the numerical solution of the two-dimensional equ ations for coupled water flow and air flow in porous media. The degree of agreement between the lab oratory results and the numerical simulation will be illustrated.

PREFERENTIAL FLOW AND TRANSPORT IN A SOIL WITH HETEROGENEOUS WETTABILITY

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The pattern of soil water movement has been measured at a site near Ouddorp, in Zeeland, The Netherlands. The soil profile is sandy, consisting of a 90 mm humic horizon at the surface, a 300 mm hydrophobic layer and an underlying hydrophilic sand. Soil wa ter content was measured using TDR sensors in a 2 meter wide by 0.7 meter trench, an d by detailed gravimetric sampling of a large soil block. Soil water content distribu tions show preferential flow along finger-like pathways. Soil sampling also yielded data on the pattern of soil wettability. In the hydrophobic layer, the preferential flow pathways ap pear to coincide with the zones of higher wettability. We will illustrate this process o f preferential flow pathway formation for the conditions at the Ouddorp site using a model of gravity-driven unstable flow and a solute transport model. The flow model is ba sed on the numerical solution of the two-dimensional, two-phase flow equations for coupled water and air flow in the soil, while the transport model is based on a Particle Tracking Random Walk solution of the two-dimensional convection-dispersion equation.

CONTINUES RESISTIVITY AND SOIL MOISTURE MEASUREMENT IN AN UNSORTED FILLING MATERIAL

Results from an experimental site in Göteborg, Sweden

Malin Norin, Gustav Lind & Mike Middleton

ABSTRACT:
Many constructions, as waterpipes and piles, in the urban ground are influenced by the soil environment. To decide how corrosive a soil is, it is common to measure the soil resistivity. Important factors influencing the soil resitivity are the soil moisture, the ion content and the soil porosity. An experimental site has been developed, existing of four opened lysimeters filled with unsorted filling material. The filling process and the soil in the lysimeters are as similar as possible. After a introductory phase with the same conditions, the soil moisture and the ion strength was varied. This paper describes the relation between the soil moisture and the resistivity and relates the measured differences between the lysimeters to the heterogeneity of the soil material and the differences in ion content.

HIERARCHICAL STRUCTURE OF UNCERTAINTIES IN UNSATURATED FLOW AND TRANSPORT THROUGH HETEROGENEOUS MEDIA

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A statistical theory has been developed for establishing the relative importance of uncertainties in input information and multiple parameter estimation in models of unsaturated flow and contaminant transport through heterogeneous media. This methodology does not rely on Monte Carlo simulations but, on properties of the cumulative distribution of output variations related to uncertainties. As a consequence, only a couple of computer trials are needed to evaluate the relationship of the variability of outputs to input uncertainties. Application of this procedure is given to one-dimensional infiltration in layered heterogeneous soils of variable thickness. The influence of geologic input uncertainties and of the spatial variability of hydrogeologic parameters on the water saturation profile is explored. The importance of this procedure lies in that it enables an assessment of which inputs need to be more tightly constrained (and by how big a factor) if the uncertainties on a suite of specified outputs are to remain within given tolerance levels. Thus, it provides a focus on the factors that control the transport of contaminants without the expenditure of inordinate effort to furnish narrower limits of uncertainty on input factors which render but little change in output uncertainties.

LABORATORY FACILITY FOR COUPLED FLOW-REACTION STUDY IN AN HETEROGENEOUS UNSATURATED SOIL.

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A laboratory facility has been developed at Ispra to study coupled reaction-flow phenomena in a spatially heterogeneous, unsaturated soil. Eighteen homogeneous cubic elements, juxtaposed and unpartitioned, form a soil monolith confined in a 60x90x90 cm plexiglas container. Each element comprises a mixture chosen amongst three textural types (sand, sand + 4% clay, sand + 8 % clay). Chemically traced water is applied at the top as a dripping regime, and eluent flow is sampled at the bottom. Real time monitoring of matric potential (pressure transducers), water content (Time Domain Reflectometry) and chemical concentration (Laser Induced Fluorescence Spectroscopy) is performed by a series of probes strategically inserted into the system. Development of a method to fill the monolith (expected bulk density = 1.5) and testing of a PC-based monitoring hardware have been satisfactorily completed. A first flow test performed with pure water provided time series of water content, matric potential, and outgoing flow. These preliminary results, presented here, are compared with the simulations of a 3D model. Further experiments will focus on flow tests using reactive/non reactive fluorophores. Understanding of flow processes, especially interface phenomena and horizontal transfer, and testing of upscaling procedures are the main objectives of the project.

SPATIO-TEMPORAL PATTERNS OF FIELD SCALE BROMIDE TRANSPORT

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Two field soils (a weakly structured sandy loam and a well structured heavy clay) with a shallow ground water table were selected to monitor solute transport through the unsaturated zone. After application of a bromide tracer, bromide concentration profiles were measured at 15 locations along a 100-m transect during seven sampling campaigns during a year. Bromide concentrations in the ground water were determined weekly. Already one week after tracer application, preferred leaching patterns were observed on the sandy loam site. These patterns were located in zones which were permanently wetter than the average field. On the heavy clay site, preferred leaching occurred due to byepass flow after heavy rainfall especially when shrinking cracks were present. The ecological risk of groundwater contamination by preferential solute transport was higher on the well structured heavy clay soil than on the weakly structured sandy loam.

APPLICATION OF DUAL ENERGY X-RAY TOMOGRAPHY TO DISCRIMINATE THE AIR, WATER AND SOLID PHASES IN SOILS

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The non-destructive technique of X-ray computed tomography -based on two energy level scanning- allowed to calculate the water, air and solid phase distribution as well as the dry bulk density and the gravimetric water content for volume elements with edge lengths of 10, 5, and 2 mm within undisturbed soil samples. Two investigated homogeneous silt loam subsoils from a Chernosem were characterized by a marked narrow spaced heterogeneity in phase composition, bulk density and water content in microscale. 2D visua-lizations in horizontal and vertical slices show marked changes of these parameters over shortest distances within slices and between neighboured slices. 3D visualizations confirm these investigations. The results offer the evidence, that it is incorrect to assume that a uniform water content distri-bution in microscale exists throughout soil samples. The sensitive dual energy X-ray tomography allows to characterize and to quantify soil tillage effects, but structural changes due to degradation or regeneration processes too.

EFFECT OF A GAP IN A LOW-PERMEABLE LAYER ON A CONTAMINANT TRANSPORT

V. I. Sabinin (Lavrentyev Institute of Hydrodynamics, Novosibirsk, Russia)

Let a three-layered ground with the middle one of a low hydraulic conductivity is drained by a river. A flow of a contamination from an earth surface or from an inner source is interrupted by an impermeable screen between the source and the river bank to prevent the river from the contamination. For a such flow processes a numerical model of two-dimensional (profile) salt transport with incomplete saturation of water is presented. Water flow is governed by Richards equation, and a salt transport is governed by an equation of a convective dispersion type. A finite-difference approximation of the problem is solved by fast iteration techniques. These techniques are of an incomplete factorization type and especially effective for a case of boundary-value problems with predominating of Neuman conditions at the boundary of an area. Computations for forecasting of the contaminant transport are held in two cases: as discribed above and with a gap in the low-permeable layer. Such gap can be at a long distance behind the source from the river. An action of the gap on the process of contamination of the river is investigated at the various distances and sizes of the gap.

EFFECT OF SOIL WATER REPELLENCY ON FLOW AND TRANSPORT

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Only very recently, it has become evident that soil hydrophobicity is wide-spread in the world. This, partly, explains that commonly used computer simulation models generally underestimate the rapidity of contamination of ground and surface water due to neglecting the presence of soil hydrophobicity and preferential flow processes through such soils. At present, no optimum management strategies exist for hydropobic soils, focusing on minimizing environmental risks while maintaining crop production. One of the reasons is that knowledge on water repellent soils is scattered among researchers of different disciplines working at different places throughout the world. This presentation aims to summarize present knowledge on water repellent soils. Origins, occurrence, consequences, modeling and amelioration of water repellent soils will be discussed.

MILLER-SIMILAR MEDIA AS MODELS FOR HETEROGENEOUS UNSATURATED SOIL

Kurt Roth (Institute of Soil Science, University of Hohenheim, D-70593 Stuttgart, Germany)

Flow and transport through globally homogeneous media are studied with the aim of elucidating the impact of local heterogeneity on global effective parameters. Simulations of flow through a single realization of a Miller-similar medium revealed the existence of a network of flow channels which depends on the flow rate. The network exhibits two complementary states which are separated by a critical region where the hydraulic heterogeneity is negligible. Transport of conservative solutes through such a medium showed many features that are also encountered in field-scale tracer experiments. In particular the simulations reproduce the breakup of an initially uniform solute pulse and the transition from an initial stochastic-convective process to an asymptotic convection-dispersion.
In this work, transport of linearly interacting solutes is studied. Information about local texture of the porous medium—as provided by Miller-similarity—is employed to define a consistent field of retardation factors. This field is found to be correlated with the velocity at high flow rates. Correlation vanishes rapidly with decreasing flow rate thereby permitting to map transport of a conservative solute to that of a linearly interacting one by using the generalized flux operator.

PREDICTING FAST TRANSPORT OF AGRI-CHEMICALS IN AGRICULTURAL TILE LINES IN HETEROGENEOUS FIELD SOILS

Tammo S. Steenhuis, Robert Wells, Marcin Bodnar, Larry D. Geohring, Rony Wallach and K-J. Samuel Kung

Pesticides traveling via preferential flow paths can be found in agricultural tile line water shortly after application. To quantify preferential transport of applied chemicals to tile lines, field experiments were performed and a simulation model was developed. The conceptual model consists of two linear reservoirs, one near the soil surface and one near the tile drain. The connection between the two reservoirs is via preferential flow paths with very little interaction with the soil matrix. The model assumes that only part of the field contributes solutes to the tile drain. The model was evaluated with data from the field experiment in which chloride, 2,4-D, and atrazine concentrations were measured on eight tile-drained plots that were irrigated twice. Atrazine was applied two months prior to the experiment, 2,4-D was sprayed just before the first irrigation, and chloride before the second irrigation. The model could simulate the observed chloride concentration patterns in the tile outflow very well. Pesticide validation was hampered because of the difficulty with independent measurement of the data needed for the preferential flow model.

FIELD SCALE SOIL HETEROGENEITY AND SPATIO-TEMPORAL PATTERNS OF SOIL WATER STATUS.

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Spatial heterogeneity of soil properties causes variation of soil water and solute transport velocities and complicates transport modeling at the field scale and leaching risk assessment. Therefore, spatial patterns of state variables underlying water and solute transport such as soil water matric potential need to be analysed with respect to spatio-temporal covariance structures. The covariance structures of space-time fields of soil water matric potential across different depths were investigated across 100-m-transects in two field soils, a sandy loam and a heavy clay in Northeast Germany. During several drying and wetting cycles, dry and wet spots conserved their locations across the field sites. The spatial autocovariance function examined for 60 measuring campaigns varied throughout the season depending upon the magnitude and direction of the hydraulic gradient. With the combined space-time fields of state variables, field sampling can be designed more efficiently and transport processes can be interpolated at the field scale.

A DETERMINISTIC APPROACH OF WATER FLOW SIMULATION IN SPATIALLY VARIABLE UNSATURATED SOIL

A.M. Zeiliguer (Moscow State University of Environmental Engineering, Pryanishnikov Str. 19, 127550 Moscow, Russia)

In our approach to spatial regionalization of water flow (WF) process three types of heterogeneity of soil structure are distinct: horizontal - in the soil map scale, vertical - in the soil horizon scale and porous - in the soil sample scale. For each type of heterogeneity appropriated technique of homogenization is used. Generated area is presented by a range of soil columns with profile divided in "pedologically" homogeneous horizons described by a set of hydraulic parameters (HP) estimated as function of physicochemical properties of structural soil elements and their spatial arrangement in soil sample scale. A hierarchical system of six (*"textural"*, *"structural"*, *"aggregated"*, *"swelling"*, *"alkali"*, *"gypso-calcareous"*) deterministic WF models for adequate soil microscopic structure (SMS) models connecting the HP with specificity of real soil has been worked out. Each type of these SMS models is identified and operated by the set of the traditionally determined soil physical (bulk density of soil and of soil structural elements, soil structural element size-distributions) and chemical properties (exchangeable sodium, gyps and calcite content). The models describing WF in these type of soil are presented as a combination of interconnected and subordinated transport and dead-end pores subspaces using the Richard's equation to simulate WF in such transport pore subspace. In dead-end pore subspace the equation of equilibrium between blocked air and compressing it water governs the redistribution of both fluids in this type subspace.

HS5 Flow and transport in unsaturated soils

03 Soil-plant-atmosphere interactions

Convener: Lindroth, A.

SENSIVITY OF OUTPUT COVARIANCE ON NON - SECOND ORDER PROPERTIES OF THE INPUT IN THE CASE OF UNSATURATED ZONE MODELS.

R. Wojcik and P.J.J.F. Torfs (Wageningen Agricultural University, Department of Water Resources, Nieuwe Kanaal 11, 6709 PA Wageningen, The Netherlands)

The classical way of doing Monte Carlo analysis is: starting from the covariance of the input, generate a great number of possible inputs, present them to the model and deduce from all generated outputs the covariance of the output. This procedure is used heavenly in unsaturated zone research.

Theoretically it is clear that if the model is non-linear (and unsaturated zone models are non-linear) the covariance of the output depends also on non-covariance properties of the input.

In this talk an easy method of investigating the sensivity of the output will be presented. This method is based on Fourier analysis and changing the phases of the transforms.

NITROGEN BALANCE AND GROUNDWATER POLLUTION BY NITROGEN OF THE IVANKOVO RESERVOIR DRAINAGE AREA (THE UPPER VOLGA).

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M.Yu. Burlin (JeoSOFT-EASTLING, 26 Podsosensky St., Moscow, 103062, Russia)

One of the principal groundwater pollutant of the Central Regions in Russia is nitrogen ($N\text{-}NO_3$ and $N\text{-}NH_4$). Its inflow occurs due to the positive nitrogen Balance. This Balance is calculated for different fields, taking into account mineral and organic fertilizers, deposition of nitrogen with rain and snow; the output of nitrogen occurs due to its consumption by plans, their sorption by soils and rocks in the aeration zone, its transformation into organic compounds and gas. The excess of nitrogen is 25-230 kg of N per ha, the highest values are connected with poultry units, cattle farms and greenhouses. When groundwater level is shallow and when the aeration zone is composed by sand and loam the groundwater pollution by nitrogen takes place. Sometimes, the quantity of nitrates exceedes MAC 5-10 times. We propose the model of the nitrate migration through nonsaturated zone till the groundwater level.

MODELLING OF PLANT GROWTH AND PRODUCTIVITY FOR SVAT SYSTEMS

A.S. Belokurov (State Institute for Applied Ecology, 44/3, Pyatnitskaya Street, 109017 Moscow, Russia)

The simulation model of the soil-vegetation-atmosphere system is considered. This model takes into account the main processes of plant growth and bioproductivity significant for scale of SVAT systems. Transpiration, evaporation from the surface of the soil, water uptake by the root system influence the moisture of the top layer of the soil. Accumulation of plant phytomass, growth, productivity of crops (as a functions of time) under weather and water limited conditions are described by processes of photosynthesis, respiration, assimilate distribution during the vegetation period. When these dependencies defined, it is possible to simulate agricultural, natural and forest systems. The model of plant growth is included as a block in the space-distributed physically based model of river basins ECOMAG, which describes the main processes of hydrological cycle of land, pollution transfer in soils, aquatic transport and bioaccumulation of contaminants. The developed dynamic plant growth model was used to forecast vegetation and land use influence on the hydrological cycle of soils and transport processes in the system soil-vegetation-atmosphere for several Russian river basins. The results of modelling were compared with data of field measures and rather good agreement was obtained.

ACID RAIN IMPACT ON UNSATURATED ZONE AND GROUND WATER.

Anna P. Belousova (Water Problems Institute, Russian Academy of Sciences, 10 Novaya Basmannaya str., P.O.Box 231, 107078 Moscow, Russia)

Acid rain produces specific impact on ground water on the urbanized areas and Oil Field. Analysis of the acid rain impact on unsaturated zone and ground water with natural HCO_3 content exposed three stages of ground water change by acid rain impact.

First stage. Supersaturating ground water by calcite, forming of the alkaline ground water. Acid rain leaches from soil and unsaturated zone rocks the HCO_3 and transports it to ground water. Concentration of HCO_3 and pH value (more than 10) increase in ground water.

Second stage. Intermediate stage. Content of HCO_3 falls far short of natural content, pH changes from 6.5 to 8.5 in ground water. Hydrochemical regime is characterized as seasonal and metastable, ground water loses own neutralizing properties, because of decreasing HCO_3 content in ground water.

Third stage. Forming of acid ground water. HCO_3 content falls far short of natural concentration in ground water, pH achieves value less than 5.

Notice that value of pH will not use as single indicator for description of acid rain impact on ground water, for this the connection between natural and observable concentrations of HCO_3 in ground water must be taken as second indicator for hydrocarbonate ground water.

TOWARDS THE UNDERSTANDING OF FOREST ROOT PROFILES

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The root distribution of forests roughly determines the soil volume that buffers water available for transpiration in periods without rainfall. Plants are supposed to optimize their root systems with respect to water and nutrient uptake. This could explain root distributions that vary with species, soils and climate. Although root depth is an important parameter in SVAT models, measurements are rarely available.

To simulate plant rooting strategies, root profile parameters of a forest hydrological model (ForHyd) were obtained by non linear optimization with respect to transpiration. The resulting root profile shows the lowest possible transpiration reduction due to drought. Root profiles were calculated for various soil types with different soil water availability and plant water requirements. Simulated root distributions are compared with sampled root systems.

SAP FLOW AND TRANSPIRATION - CAPACITANCE EFFECT MODELLED BY SPAC

E. Cienciala and H. Eckersten (SLU, Department of Soil Science, P.O. Box 7014, S-750 07 Uppsala, Sweden)

A soil-plant-atmosphere continuum (SPAC) model was applied on large coniferous trees to assess the capacitance effect when relating sap flow and transpiration courses. On a daily timestep sap flow rate is sometimes used to calculate stomatal/canopy conductance from the reversed Penman-Monteith equation. On a diurnal courses this relationship depends on the differences between conditions determining transpiration (in plant and atmosphere) and uptake (in soil and plant), and the availability of plant water. Using a one-dimensional non-steady state SPAC model those processes are analysed. Errors, as compared to using simple cross-correlation to derive a time shift between the sap flow and transpiration fluxes, are significantly reduced.

CALIBRATION OF A ONE-DIMENSIONAL MODEL FOR SIMULATING WATER TRANSPORT IN THE UNSATURATED ZONE.

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L.E. Haugen (Department of Soil and Water Sciences, Agricultural University, P.O.Box 5028, N-1432 Aas, Norway).

Field data have been collected for the calibration of a model for water transport in the unsaturated zone. Two plots were sown with wheat, whilst the other two were left fallow. The matric potential was measured at 5, 20, 40, 60 and 80 cm below surface. Model input parameters as crop height and leaf area index were measured. Soil samples were taken for the determination of soil physical characteristics. Through simultanuous measurements of the matric potential at different depths under both crop and fallow conditions it was concluded that the root depth did not extend beyond 50 cm below soil surface. The simulation was carried out with the SOIL-model, developed at the Swedish University of Agricultural Sciences. The model was calibrated against the measured values for the matric potential. Full compensatory uptake of water was assumed when a deficit of water occured in a certain layer while the critical potential for water uptake was set at - 450 cm. Simulated values fit reasonably well with measured values for the matric potential at depths of 20 and 40 cm below the soil surface. For the deeper layers, the simulated matric potentials were lower than the field measurements, indicating too much water uptake. Simulating with only partly compensatory uptake did not result in improved fit. Neither did a change in the level of the critical potential for water uptake.

ROOT SYSTEMS ARCHITECTURE AND MODELLING OF WATER UPTAKE BY PLANT ROOTS

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L. Pagès (INRA, Unité de Recherche en Ecophysiologie et Horticulture, Site Agroparc, 84914 Avignon cedex 9, France)

Studies of water uptake in soils have generally been conducted with two kinds of approach: the "single root" model and the "macroscopic" approach which defines a root sink term in the Darcy-Richards equation. In these approaches, root system heterogeneity and control of water absorption by the plant are extremely simplified, leading to numerous formulations of the sink term. A better description of root system architecture and physiology of uptake may help in studies of water uptake. As realistic numerical simulation of root systems growth and architecture are now available, we present a new way for modelling water uptake, from the single-root to the root system level, by coupling models of root system architecture and water absorption. The simulated root system is divided into a sequence of small segments for which hydraulic parameters (axial and radial conductances) are given. From known boundary conditions (soil water potentials, transpiration rate or water potential at base of the stem), the resolution of the flow equation in the root system gives water potentials and fluxes to and up each roots of the system and water potential or transpiration rate at the stem base. Measured water fluxes profils along a root are reproduced by the model. Influence on water uptake of some configurations of root systems, soil water potential profil, root conductances are examined.

WATER USE, UPTAKE AND NITROGEN EXPORT IN A CEREAL ROTATION INCORPORATING PERRENIAL PASTURE.

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Four years of water balance monitoring during a cereal rotation revealed phase differences to conserve water and nutrients for herbage uptake and production. Continuous measurement of soil water content with Time Domain Reflectometry combined with lysimeter data for evapotranspiration enabled determinations for rates of plant uptake and drainage export from the root zone. Nitrogen uptake and leaching were evaluated from regular sampling of soil mineral nitrogen and the soil solution. The most effective control of nitrate leaching was achieved with a perennial pasture involving lucerne to benefit ensuing crops with greater potential for resource uptake. Lucerne uptake was extended over soil depth and time relative to the other annual components of the rotation, in reducing the threat of leaching loss in subsequent phases. The implications of enhanced conservation and nitrogen are discussed for regional environmental protection and for overcoming soil acidity.

MULTI-METHOD APPROACH TO ESTIMATE FOREST EVAPOTRANSPIRATION (THARANDTER WALD)

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Evapotranspiration of a 28m tall, 106 years old spruce forest at the Anchor station „Tharandter Wald" is determined by a variety of methods. Following micro-meteorological methods were applied: the eddycovariance-engery balance method (ECEB), Bowen ratio energy balance method (BREB) and the aerodynamical method. The analysis is based on measurements of sensible heat with sonic anemometers, radiation components, soil heat, wind and temperature profiles. In dry periods evapotranspiration can be estimated from tensiometer data with help of the soil moisture retention curve and from evapotranspiration induced variation in the water gauge of a small river („Wernersbach").
Sap flow and stem circumference measurements were also made on different trees in the vicinity of the measuring tower. This allows the determination of tree transpiration for a known active sap wood area. In stem circumference measurements daily reversible changes were observed. These changes occur in dry periods, when water transport from the soil in the stem is smaller than water loss through stomata. The comparison of altogether 7 methods to describe the water flux relationship of the Anchor station favors the ECEB method for long-term evapotranspiration measurements due to its reliability and time resolution. Sap flow, soil hydrology and water balance methods add information on vertical and horizontal source distribution, as well as cross-check against well established long-term estimates on a yearly basis.

CARBON DIOXIDE FLUXES PARTITIONING AT SOIL AND CANOPY LEVEL IN AN EVERGREEN MACCHIA FOREST ALONG A SEASONAL TREND

S. Greco, S. Dore, G. Tirone, G. Muratore, R. Valentini (Dep. of Forest Environment and Resources, University of Tuscia, I-01100 Viterbo, Italy).

Eddy fluxes measurements were carried out during summer 1996 over a mediterranean macchia ecosystem mainly constituted by *Quercus ilex* L. The seasonal trend of canopy fluxes of CO2 is compared with the soil efflux and the moistuire regime. Soil Co2 efflux was measured by chambers on a number of replicates throughout the season. It is evident the effect of water stress on both canopy assimilation rates and the soil efflux which drammatically decrease following the period of water shortage.
Some considerations on the carbon uptake of such vegetation cover and the effects of biological controls are presented

COMPARISON OF MEASURED AND SIMULATED EVAPOTRANSPIRATION OF SOYBEAN, FABA BEAN AND MAIZE USING CROP GROWTH MODELS

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In this case study, the agreement of simulated Evapotranspiration (ETP) of different crop models (and methods) with measured data in diffenent phenological stages is analysed. In general physiological control (stomata regulation of transpiration) and the varying degree of canopy closure (transpiration vs. evaporation) are different for various crops and development stages.
In a field experiment near Vienna (Marchfeld) agrometeorological investigations on soybean, faba bean and maize were done during the growth period in 1992. Evapotranspiration was determined using the Bowen Ratio Energy Balance (BREB) method, the determination of the soil water content was done with gypsum blocks and the time domain reflectometry method. Atmospheric parameters were recorded at a specifically designed agrometeorological station. Crop models for soybean, faba bean and maize (MACROS, CERES-Maize, SOYGRO and CRPSM) were used to simulate evapotranspiration, soil water balance and crop growth. It is shown that parametrization of calculation of ETP in crop models should take soil, plant and atmospheric parameters into consideration. Especially plant parameters for calculation of ETP should be sensible to the development stage of the crop. Basically, calculated soil water content and root depth should fit to the real conditions.

VARIABILITY OF THE EXCHANGEABLE CATIONS IN A LOESS TOPSOIL DURING THE GROWTH OF WINTER WHEAT

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At four locations of a loess/ loessloam hillside which is used as farmland the temporal variation of exchangeable cations and cation exchange capacity were measured to monitor the influence of plant growth on cationic soil composition and soil solution movement. This work was done in the course of a two year old bromide field tracer experiment that evaluated the temporal and spatial variability in the water balance and plant growth over the hillside. Different soil types were sampled from four locations of the sloped test area. At the locations soil cores were extracted in the uppermost meter between begin of sprouting and blossom twice a month. The samples were devided into sections of 0-30cm; 30-60cm and 60-100cm length. A decrease of 10-40g/m^2 in exchangeable potassium was measured that could be explained by plant uptake. Also an increase up to 80 g/m^2 of exchangeable Magnesium was measured. This is an order of magnitude above the estimation of plant influence and soil weathering. The dynamic of the cations could be well explained by the water characteristics of the different positions. This work is sponsored by the DFG-Graduiertenkolleg "Ecological Watermanagement".

Siberian Programme of GEWEX Asian Monsoon Experiment

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Last years scientists from different countries pay more and more attention for studying the different aspects of Water and Energy cycle in Northern Permafrost regions. Environment conditions develop there under great variability of climate. From the other side these vast regions influence greatly the surrounding environment. The specifities of processes responsible for regulation of Water and Energy cycles in Permafrost regions, numerous direct and inverse links are not studied sufficiently till now. Among international programmes in which great attention is paid for study of specifities of Water and Energy cycles under permafrost conditions, the special place is occupied by Siberian subprogramme of GEWEX Asian Moonsou Experiment (GAME). Cooperation between Russian and Japan National Committees on GAME forms the basis for realization of the Siberian Programme. Main objectieves of Siberian Programme are: 1. To understand the atmosphere-land surface interactions for permafrost conditions of Siberia through esteblishing the localscale intensive meteorological and hydrological observations.ground based remote sensing,aircraft measurements as well as radar and satellite observations. 2. To understand multi-scale physical processes associated with energy and water cycle in Siberian area. 3. To clarify the long-term variation of land surface, climatic characteristics and energy/water cycle in Siberia. 4. To adapt GCMs. SVAT models to permafrost conditions, and develop macro- and mesoscale hydrological models and limited-area coupled model. 5. To establish local and regional dataset of hydro-meteorological and geographycal elements and satellite data for GAME yearsas well as past years.

MODELING MICROWAVE EMISSION OF LAND SURFACE AT L-, P-BANDS IN THE FRAME OF THE GENERAL CIRCULATION MODEL

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The General Circulation Model is the key component in study of global water atmospheric dynamics. One of basic parameters of the model is a soil moisture which can be determined with microwave radiometric method at the decimeter wavelength range. In this paper a capability of passive microwave method based on numerical modeling the earth surface brightness temperatures (BT) with the spatial resolution of 4° latitude by 5° longitude is analyzed. The model of microwave emission accounts the contribution of natural emission of the ground, vegetative covers, and sky radiation. The simulation was used to study a seasonal dynamics of BT of different land surface types: desert, tundra, deciduous, coniferous forest and tropical rainforest, prairie and steppe. The radiation model of ground assimilates such parameters as the emission, wavelength, observation angle, polarization, Fresnel reflectivity, volumetric soil moisture content as well as the surface temperature and attenuation of radiation in a vegetative cover and atmosphere. The canopy opacity depends on vegetation biomass, water content, geometry and plant temperature. The contribution of sky radiation was defined as absorption in oxygen and ionosphere and reflection from a land surface of cosmic background radiation, which dependes on geographical coordinates. To research the BT spectrum of a land surface the archival and climatic data of soil and vegetation types, moisture and temperature of soil surface, vegetation biomass and atmospheric meteoparameters were used.

ESTIMATION OF SCOTS PINE ECOSYSTEM WATER BALANCE – EMPIRICAL FIELD EVIDENCE

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Water balance of a 34 year old Scots pine stand was monitored in Southern Finland. Eddy covariance (Solent ultrasonic anemometer and LI-COR 6262 gas analyser), shoot transpiration (cuvettes with closing lids and URAS 4 gas analyser), stemflow (Dynamax) and soil water content (64 TDR sonds) measurements were conducted simultaneously. We have compared the outputs of different methods and found them to give comparable results within shortcomings special to each method. The advantages of independent simultaneous measurements to overcome the shortcomings are discussed.

APPLICATION OF THE FOREST-SOIL-WATER MODEL (PnET-BGC/ CHESS) TO THE LYSINA CATCHMENT, CZECH REPUBLIC

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A new, fully linked model was developed to simulate forest growth and geochemical processes with emphasis on element cycling (Santore, dissertation in progress). The PnET-BGC model expands calculation of forest productivity and water use of the earliest version of the PnET model (Aber & Federer 1992, Oecologia 92: 463) to include decomposition processes and cycling of major elements. The CHESS model simulates abiotic soil chemical processes (Santore & Driscoll 1995, Soil Sci. Soc. Am. Spec. Publ. 42: 357). The study catchment consists of Norway spruce (*Picea abies)* plantations on Spodosols located in a highland of western Bohemia (Krám et al. 1995, Water Air Soil Pollut. 85: 1831).

Forest growth, hydrology and biogeochemistry of the catchment were simulated for the period 1550-2050. Simulated concentrations of SO_4^{2-}, F^-, Ca^{2+}, Mg^{2+}, Na^+, K^+, Fe_T, Si, and monomeric Al were similar to streamwater concentrations measured in 1990-1994. The model slightly overpredicted H^+, Cl^- and DOC and highly overpredicted NO_3^- and especially NH_4^+. A reduction of S inputs to 30% of 1991-1994 values in 1995-2050 showed a decrease in base saturation (BS) of 2.5% between 1995 and 2050. Inputs of S reduced to 10% showed an increase in BS after 2030. Scenarios of improved deposition of S showed slow desorption of previously stored S to drainage water.

ANALYSIS OF NON-LINEAR HUMUS ACCUMULATION MODEL INCLUDING NEGATIVE FEEDBACK WITH HIGH BIOLOGICAL PRODUCTIVITY

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The stability of a 'soil humus - plant cover' system is considered using a mathematical model of the organic carbon cycle in natural phytocenons. Humification and mineralization of plant residuals, humus mineralization and abiotic input are the processes governing the state variables - the carbon contents in soil humus and in litter. The model is based on the equations proposed by I.M. Ryzhova (1991, 1992), modified to describe the suppressing effect of humus excess on plant productivity. The states of equilibrium and their stability are determined in relation to parameter values. The analytical expression for separatrix is received.

SOIL AND ATMOSPHERE CONTROLS ON EVAPOTRANSPIRATION IN A PINUS SYLVESTRIS FOREST PATCH IN A MEDITERRANEAN MOUNTAIN AREA

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The study of the evapotranspiration processes of Pinus sylvestris patches overgrown in abandoned farming terraces in a Mediterranean mountain area (Prepyrenees) has been performed since 1993 with the aim of understanding the consequences of land use change in water resources. Non-micrometeorological methods are used to measure evapotranspiration and water transfer in soils both in dry and in rainy conditions. Following these purposes the study area is monitored, at detailled time step, with reference meteorological instruments, sap flow probes, rainfall interception devices, TDR and tensiometric devices. Current research is focused on the study of the soil-plant-atmosphere system analyzing the role of atmospheric demand and soil water conditions on actual measured evapotranspiration.

Initiatives in Biosphere-Atmosphere studies in the European Arctic.

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Tundra covers the ice free areas of Greenland and Svalbard and also the mountainous and northern regions of the Scandinavian peninsula and European Russia. Under a European Union funded programme LAPP (Land Arctic Physical Processes) the surface fluxes of water, carbon dioxide and methane are being measured at a range of sites: in East Greenland, Svalbard and northern Finland. Measurements are primarily with eddy correlation, to give a patch scale flux, but are supported by chamber measurements. A wide suite of supporting measurements are also made including the radiation balance, soil water and temperature and permafrost depth. The first results show a wide range of fluxes (typical midday August uptake of CO_2 ranges from 0.009 to 0.2 mg m^{-2} s^{-1}) which is not only determined by the temperature gradient but also soil water and other edaphic factors. It is evident that a knowledge of the water and thermal regimes in the soil are vital to an understanding of the biospheric processes in the Arctic.
New initiatives include an extension of measurements into European Russia and a detailed modelling of hill slope hydrological processes in permafrost regions and their link to biospheric processes.

THE IDENTIFICATION OF AN EFFECTIVE ROOTING DEPTH FROM SAP FLOW DYNAMICS WITH A NEURAL NETWORK MODEL

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The water use of a single tree is the result of the evaporative demand and the availability of soil water. The sapflow dynamics of a single tree therefore contains information on root water uptake mechanisms. Because of their complex nature, feedback mechanisms are difficult to quantify with a deterministic model. In this study we used a neural network to describe the sapflow dynamics of individual pine trees in a forested ecosystem and to assess rooting depths.

A neural network recognizes complex patterns without using deterministic relations. The overall-fit error of a neural network is an indicator of how good the output data can be modeled from the input-data. Provided with the right input like micro-meteorological data and information on the soil water status, a neural network was trained to describe the sap flow dynamics of an individual tree satisfactory. A rooting depth could be determined by stepwise adding information on the soil water profile to the network. The results show the potentials of the use of artificial neural networks to understand the water use of trees.

MODELING IRRIGATION STRATEGIES USING A SOIL-PLANT-ATMOSPHERE MODEL

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This study reports on the validation of a numerical model developed for simulating water transport processes in the soil-plant-atmosphere system. The model performs the soil water balance, evaluates the crop water consumptions also when plants suffer water stresses, thus enabling the effects of different irrigation strategies on crop yield to be assessed. Water uptake by plant roots is described by a sink term which is added to the Richards equation employed to simulate water movement in soil. The Penman-Monteith and Ritchie relationships are used to evaluate water losses by evapotranspiration from soil and plant. Internal water storage and stomatal response to the environmental conditions are also considered. Data for validation were gathered from two sets of field plots cropped with pepper (Capsium annum, L. cv. "Yolo Wonder") and bean (Phaseolus vulgaris, L. cv. "Slankette"), respectively. During the experiments, irrigations were properly performed so as to control water applications to each crop and to induce different levels of water stresses in the plants. In all of the considered cases, the model simulates accurately the time evolution of soil-crop processes and has proved capable of providing a realistic description of the daily fluctuations of water status in the plant not only in the case of optimal water applications, but also at the onset of plant water stress. A sensitivity analysis has also showed that the model is stable against parameter uncertainty and rather sensitive to the parameters which describe density and resistance of the roots.

DYNAMICS OF SHOOT WATER POTENTIAL IN *PICEA ABIES* DEPENDING ON AIR AND SOIL WATER STATUS

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To explore the combined effect of soil water availability and atmospheric evaporative demand (**AED**) on daily dynamics of the shoot water potential (Ψ_x) in middle-aged trees of *P. abies*, an empirical model was developed:

$$\Psi_x = \Psi_b + c_1 \cdot (1 - e^{\frac{c_2 \cdot VPD^{c_3}}{\Psi_b \cdot c_4}}),$$

where Ψ_b is the base water potential (an index of the soil water availability), **VPD** is the atmospheric vapour pressure deficit, and c_1, c_2, c_3 and c_4 are constants. Under high soil water availability and low **AED** the dynamics of Ψ_x is strongly governed by **VPD**: Ψ_x follows sensitively the current level of **VPD** both in fore- and afternoon. At high **AED**, after Ψ_x has fallen to certain level, the stomata will significantly narrow and further rise in **VPD** after midday will be accompanied by increase in Ψ_x. In afternoon Ψ_x matches with the changes in **VPD** as well, but it demonstrates a hysteresis. The impact of **AED** on shoot water supply significantly weakens with decreasing soil water availability due to more efficient stomatal control on transpirational water loss from foliage. Under soil water shortage Ψ_x responds to the course of **VPD** only in the morning. Exceeding a threshold value, Ψ_x causes a stomatal closure preventing its further decline. The threshold of Ψ_x inducing sharp increase in stomatal resistance declines with decreasing soil water availability.

APPLYING OF PLANTS IN WATER PURIFICATION PROCESS

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There are 150 species of hydromacrophytes in Poland. Most of them can be used for the plant method in sewage purification, in final cleaning treated effluence, to dry liquid sludge or for indicating non-polluted water. It is proposed to put into practice in treatment plant a lot of taxons simultaneously. It would increase pollution reduction, improved cleaning efficiency, keep persistence and aesthetic aspects, prolong function in the growing season. Biological and ecological characteristic also environmental feature macrophytes are present. They should be taken into account for purifying objects preparation. Plants composition should be arranged to improve operation and reliability of the waste water treatment plants and effluent quality. Zone and mosaics structures of the purifying biocenosis are also important. Concept of three series reservoirs purifying the waste water in this poster has been presented. Each of the habitat have been proposed. The base of this concept are many years observations and investigation of the water plants, eutrophic sites and outlets of waste water. Model effluent reservoirs with implanted hydromacrophytes are operated currently on Department of Natural Bases of Environmental Engineering Experimental Ecological Field.

REGIONALIZATION OF EVAPOTRANSPIRATION PREDICTION

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There exist quite a few methods to predict daily rates of actual evapotranspiration (ET_a). Dependent on the kind of estimation routine which is used, different meteorological parameters find an impact on the calculation. Most commonly, these parameters are: temperature, vapour pressure (deficit), solar radiation and windspeed. Very often ET_a calculations in catchment studies are based only on data, which are taken at a central meteorological station. Spatial variations of these parameters – due to the influence of landscape topography – are not considered. In this presentation we will show predicting methods for the extrapolation of meteorological parameters within a small agricultural catchment ($6\ km^2$) considering landscape topography (e.g. slope, exposition). A comparison between measured and predicted data will demonstrate the suitability of the used predicting scheme. Distributed simulations of the waterbudget within the catchment indicate very high overestimations of predicted ET_p and ET_a rates, when topographic effects are neglected.

CHANGES IN WATER REGIME OF MODEL FOREST ECOSYSTEMS UNDER ELEVATED CO2 AND N DEPOSITION

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In this project we assessed the influence of elevated atmospheric CO_2 concentration and nitrogen deposition on the water regime of a model forest ecosystem for two different soils. Four replicate lysimeters were installed for each combination of soil and treatment. The water balances of the 32 lysimeters were determined once a week.

During winter and spring differences of actual ET between individual lysimeters as well as between treatments were found to be very small indicating that differences in ET between the lysimeters during the vegetation period were rather due to plant than to soil factors. In accordance with our hypothesis, elevated CO_2 reduced evapotranspiration on the acidic soil in summer. On the calcareous soil such an effect was only seen in July. Elevated nitrogen deposition was found to increase evapotranspiration on both soils.

ESTIMATION OF EVAPORATION FLUXES FROM TDR MEASUREMENTS OF NEAR-SURFACE WATER CONTENT

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During the 1994 NOPEX (NOrthern hemisphere climate Processes EXperiment) field campaign near Uppsala, Sweden, TDR measurements were made using a multi-plexed TDR system with a 30 min. sampling rate. The high sampling rate was selected in order to compare TDR measurements with eddy correlation measurements of atmospheric fluxes of water vapour using a water balance approach. The time series of TDR measured water content, however, showed strong apparent temperature effects seriously degrading the temporal resolution of the measurements. An empirical algorithm requiring no specific soils information was found adequate for removing most of the diurnal variation in water content due to temperature. The time development in corrected water content measured using vertical TDR probes sampling the top 20 cm of the soil profile was found to approximately follow observed evaporation fluxes for a four day period with no measurable rainfall.

WATER TRANSPORT AND CONTROLS IN A Q. ILEX FOREST IN CENTRAL ITALY

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A study was conducted in the Castelporziano (Rome) natural reservation as part of the Euroflux project with the aim to investigate the effect of the summer drought on the soil - plant - atmosphere water transport. The vegetation is constituted by a 30 years old Quercus ilex forest and the measurements have been carried out from June to December 1996. Water transport and transpiration were studied with six radial sapflow meters, using the stem heat balance method, implanted in six Quercus ilex trees of same diameter and age.
The saplow measurements were combined with soil humidity (by TDR) and meterological variables, including plant phenology and growth.
Results are presented concerning the effects of soil moisture on tree transpiration, the relatiosnhips between tree transpiration and overall canopy water exchanges mesasured by eddy covariance and the effects of biological and meteorological variables on the water transport.

SCREENING SENSITIVITY ANALYSIS OF THE MODIFIED WAVE-MODEL

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Integrated soil-crop-atmosphere models are able to quantify the effects of climate change on crop production and the fluxes of the soil water balance. Within this study, the physical-based integrated, local scale, soil-crop-atmosphere transport model WAVE (Vanclooster et al., 1994) was adopted to simulate soil water transfer in the soil-atmosphere continuum under Southern European conditions. A modified evapotranspiration model was implemented in the WAVE model, as to avoid the definition of the reference evapotranspiration and the crop specific Kc-factors as external boundary conditions. This model consists of a mechanistic evaporation scheme, based on the formulation of Shuttleworth and Wallace (1985). The parameters of the aerodynamic and crop surface resistance terms are calculated in terms of simulated crop LAI, crop height, root growth and root water-uptake, while the parameters characterizing soil surface resistance are derived from the dynamic solution of the water flow equation. The modified version of the WAVE model was calibrated using field data collected at the experimental field of La Côte St.-André, France, followed by a screening sensitivity analysis. From this analysis it was concluded that the surface hydraulic properties control the evaporation to a large extent. Therefore, future research efforts should address refinement of the process description of the effective soil surface resistance.

Long-term modelling of soil water balance at a spruce site in the Black Forest/Germany

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The occurrence of high-altitude needle tip-yellowing in spruce in the 80's was repeatedly related to dry years and in general explained as a consequence of magnesium deficiency. To test this hypothesis the soil water regime of the mountain site Schluchsee was analysed. In order to get a high resolution of the soil water content in space and time, a soil water model was fitted with soil water data from a 9 years' measurement period. For modelling the division of potential evapotranspiration into interception and transpiration xylem flow data was used. Actual evapotranspiration and deep seepage were checked with the water balance of the small experimental catchment. The model enables retrospective simulations of daily soil water balance with climatic data from neighbouring meteorological stations 25 years before measurement started at this site. In 1976 and 1983 the organic layer showed parching of the soil near the permanent wilting point. In contrast to the dry situations in 1991 and 1992, the dry periods in 1976 and 1983 commenced shortly after the start of the growing season when spruce has its peak demand of magnesium. Magnesium supply comes at this site from the organic layer and it is hypothesized that early summer droughts induce nutritional disturbances.

HS5 Flow and transport in unsaturated soils

04 Multiphase flow and transport behaviour in soil/aquifer systems

Convener: Mackay, R.
Co-Convener: Grathwohl, P.

PERMEABILITY OF NONAQUEOUS PHASE LIQUIDS IN POROUS MEDIA

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A limiting factor in predicting the simultaneous flow of water and a nonaqueous phase liquid (NAPL) in a porous medium is the accurate determination of the permeability of the NAPL as a function of capillary pressure or saturation. A flow cell was developed in which the degrees of water and NAPL saturation can be adjusted throughout the flow cell in such a manner that the capillary pressure is the same over the entire height. The adjustments are made by extracting water from the porous medium through a ceramic cylinder covering the entire inside wall of the cylinder containing the porous medium. The top and bottom of the flow cell are connected to constant head devices to maintain steady state flow conditions for the NAPL at each of the imposed values of the capillary pressure. Permeabilities are calculated from the difference in density between water and the NAPL and the corresponding flow rates.

DEPENDENCE OF THE HYDRAULIC AND PNEUMATIC CHARACTERISTICS OF SOILS ON DISSOLVED ORGANIC COMPOUNDS

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This work focuses on the quantification of the effects of dissolved organic compounds on the hydraulic and pneumatic characteristics in soils. Butanol was chosen as the model compound to vary the physical properties of the wetting phase. Column experiments were performed with a quartz sand mixture using air as nonwetting phase and water as well as 2% and 6% (by weight) aqueous butanol solutions as wetting phase. The capillary pressure, the hydraulic and pneumatic permeability functions were determined as functions of the wetting phase saturation. The capillary pressure–saturation curves were scaled according to the surface tension ratio considering water as the reference fluid. Little hysteresis was found in the hydraulic permeability curves and all curves were described with a unique function. The air permeability curves determined for the different wetting fluids agreed well and the emergence point of air flow was a function of the wetting fluid saturation only. The results presented indicate that the effects of varying wettability on the constitutive relationships of the porous medium caused by dissolved organic compounds can be predicted from the knowledge of one set of experimental reference data.

MODELLING OF DISSOLUTION AND KINETIC MASS TRANSFER OF MULTIPLE ORGANICS AT A FIELD SITE

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Residuals of organic solvents in groundwater are known to act as persistent sources of groundwater contamination. Understanding the mechanisms of dissolution and mass transfer from these sources into the groundwater is critical to the evaluation of remediation options. The study of the emplaced field source at Borden, Ontario, Canada helps to develop this understanding. The source contains a mixture of three DNAPLs (TCM, TCE, and PCE) emplaced under controlled conditions in a known volume of sandy aquifer material below the watertable. The present work focuses on modelling the dissolution and mass transfer from the DNAPLs to the aqueous phase and on predicting source evolution to complete dissolution. A kinetic mass transfer model is calibrated to time-dependent aqueous concentrations measured at a sampling fence located 1 m downgradient of the source. It is found that the mass transfer rate can be expressed in terms of the aqueous diffusion coefficients of the individual DNAPLs, a geometry factor representing the porous medium, a velocity factor representing the flow system, and an accessibility factor representing time-dependent DNAPL-specific processes. The relative dissolution rates of the three organics are found to be well represented by Raoult's law. 3D flow of groundwater around the low-permeability residual source, as well as flow through the source, are found to affect the mass transfer mechanism. As a result, the mass transfer model cannot be defined entirely in terms of primary system characteristics, but must be calibrated empirically.

TCE REMOVAL BY PUMP-AND-TREAT WITH AND WITHOUT SURfACTANT

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A 1.7 * 1 * 0.05 m flow cell was packed with a heterogeneous porous medium, resembling an actual trichloroethylene (TCE) contaminated US Department of Energy site. After infiltration and redistribution of two TCE spills, a two-well system was used to inject clean water and extract contaminated water. After 10 days of pumping, the clean water was replaced by a 1 % T-MAX-80 surfactant solution. The surfactant flushing continued for several months. Throughout the experiment, a fully automated dual-energy gamma radiation scanner was used to measure TCE saturation at several hundred locations. Water was extracted from 20 ports and analyzed for dissolved TCE. Results show that the pump-and-treat technique is not effective in removing TCE. Adding surfactant resulted in higher removal rates, but also in unwanted mobilization of liquid TCE and the formation of unstable dense contaminant plumes. Residual TCE and small pools were easily removed, but a larger pool was removed only after months of flushing.

ARE THE HYDRAULIC AND THE GEOCHEMICAL PROPERTIES OF GRAVELLY AQUIFERS CORRELATED WITH THE MAIN LITHOFACIES?

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Various aquifers in the Alpine and the Perialpine valleys are made up of coarse fluvial sequences. These sequences may be composed of a limited number of architectural elements which can be recognized as mappable reflections on ground-probing radar profiles. The architectural elements themselves may be composed of a few lithofacies. The results of hydraulic testing and geostatistical analysis showed marked differences in the hydraulic properties between the different lithofacies compared with the variability of the individual lithofacies. The frequency and the size of one particular lithofacies, made up of an open framework of normal graded cobbles (the openframework gravels), determine the variance of ln(K) and the correlation length, but they do not necessarily correlate with the effective K-value. Based on these findings, we expected to find also a relationship between the different lithofacies and the geochemical properties which may be relevant for transport processes. Specific surface area (SA), organic carbon (OC), carbonate content ($CaCO3$) and cation-exchange capacities (CEC) have been measured for the grain-size classes < 0.063, 0.063-0.25 and 0.25-0.5 mm. Clay minerals were only semi-quantitatively determined. The data show that the BET surfaces and the content of organic carbon is slightly higher in the highly conductive open framework zones and the porous sand. However, the values of the measured geochemical parameters of the other lithofacies do not follow any general trends.

MAGNETIC RESONANCE IMAGING STUDIES OF DISSOLUTION KINETICS IN POROUS MEDIA

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Magnetic Resonance Imaging (MRI) has been used to investigate the dissolution kinetics of hydrocarbons from a random packing of spherical ballotini. the results of which have been compared to predictions provided by various soil remediation models which have appeared in the literature. MRI has been shown to be particularly powerful in such studies due to it being non-invasive, chemically selective, quantitative and able to attain a resolution down to 190 μm. Octanol was imbibed into the bed containing the ballotini at a constant rate, after which water was flushed through the bed to effect dissolution. A number of 3-dimensional selective images were acquired of the octanol, exploiting its shorter relaxation properties relative to water, during the course of the dissolution, from which an unambiguous saturation level could be attained. This process was repeated for a variety of flushing rates. In addition, by application of an in-house algorithm, characteristics (volume,area,shape) of individual ganglia could be extracted, as dissolution proceeded. The surface area per unit volume of the ganglia in contact with solid and in contact with water, was hence directly attainable, a notable omission from all previous experimental investigations. Such a value was found to have a linear dependence upon saturation, the slope of which was independent of flushing velocity, and dependent upon initial saturation. The latter observation was validated by MRI velocity images of water, acquired of an identically constructed bed, which showed that an increase in velocity has little effect on the flow pattern established.

WATER RETENTION, GAS PERMEABILITY AND PORE STRUCTURE IN SHEARED GRANITE

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Water retention and gas permeability functions of sheared granite were measured in the laboratory. Parametric models were applied to the experimental data. The retention data were described best by the van Genuchten model. Using the emergence-point approach, the best prediction of relative gas permeability was obtained with the van Genuchten-Mualem model.

In order to explain the measured properties, the fracture structure within the sheared granite was examined. A procedure for the visualization of the pore structure of sheared granite samples was developed. After imbibition with resin containing a fluorescent dye, the samples were sectioned stepwise. Photographs taken from the different sections were processed with routine image-analysis procedures. Three dimensional reconstructions of the pore space were obtained. Taking the aperture density distribution as an example, it was shown that by means of image-analysis procedures, parameters for the application of flow and transport models in sheared granite can be obtained.

CAPILLARY BEHAVIOUR OF TWO-PHASE FLOW IN AQUIFER SYSTEM

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Capillary effects of two-phase flow in aquifer system have been studied both experimentally and numerically to define the contaminants migration condition when the contaminants are a distinct fluid or gaseous phase. The peculiarity of the Non-Aqueous Phase Liquid (NAPL) motion in the water saturated porous media has been studied experimentally on transparent model of porous media. The fractal dimensions as far as the self-similarity scale of the interfacial boundary were measured. Taking into account both interfacial boundary micromechanics and small droplet capillary entrapment the numerical modelling of the NAPL motion was done in dependence from pore space geometry. The statistical modelling of the small droplet movement was done too and the critical size of the NAPL droplet which can migrate in aquifer has been obtained. The convective diffusion of the salt-water solution in unsaturated aquifer was studied experimentally. The small droplets increase the flow scale and longitudinal dispersivity is increased too.

THE INFLUENCE OF HEAVY METALS DISTRIBUTION ON THE TRANSPORT OF ORGANIC MATTER IN SOIL

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The adsorption of organic matter (OM) to a mineral matrix is one of the main ways of its immobilisation and conservation. We have estimated the influence of heavy metals pollution on the interaction of organic molecules with minerals in soil. Nevetheless, there have been no theories of selective interaction between organic matter and mineral components. We used an approach recently proposed by Nechaev to describe the interaction of OM with minerals. The main idea of this technique is that interaction depends on the ionization potential of OM and characteristic potentials of minerals, so called "resonance potentials". These potentials determine the possible interaction of the mineral with the OM, depending upon if the resonance potential of the mineral corresponds to the ionization potential of OM. The adsorption centers of different clay minerals were studied. It was shown that a number of adsorption centers, i.e. a variety of adsorbed OM, and the degree of OM adsorption are higher in soil contaminated by heavy metals compared to uncontaminated case. The deposition of heavy metals in soil transfers OM from dissolved state to a linking one, and changes the physico-chemical properties of soils.

PREDICTING TWO-PHASE RELATIVE PERMEABILITY-SATURATION-CAPILLARY PRESSURE RELATIONS IN MIXED-WET POROUS MEDIA.

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A parametric two-phase oil-water relative permeability/capillary pressure model was developed to describe fluid behavior in mixed-wet porous media in which the smaller pores are water-wet and the larger pores are intermediate- or oil-wet. A saturation index, which can vary from 0 to 1, is used to distinguish the water- from the intermediate- or oil-wet pores. The fully hysteretic capilla ry pressure model is capable of describing main-drainage and scanning-path relat ions, including negative oil-water capillary pressures. The model is tested by e valuating how well it can describe measured mixed-wet capillary pressure data and by comparing relative permeability predictions to those of a water-wet model with a similar pore structure. In addition, efforts are underway to directly measure the relative permeabilities of oil in the presence of water for both water- and mixed-wet porous media. Preliminary results suggest that the model is capable to predict characteristics of mixed-wet porous media.

DISSOLUTION OF POLLUTANTS FROM POOLS OF DENSE NON AQEUOUS PHASE LIQUIDS (DNAPL

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Coal tar - a common contaminant at former gas manufacturing plants - belongs to the dense non aqueous phase liquids (DNAPL) and comprises mainly polycyclic aromatic hydrocarbons (PAH). Coal tar can be found as residual phase in the subsurface distributed as droplets ('blobs'), which may accumulate in pools above zones of low permeability. The dissolution rates of PAH from blobs and pools determine the risk to groundwater quality. The dissolution rate is controlled by diffusion and depends on the equilibrium water solubility of the PAH, the DNAPL/mobile water interfacial area and the flow velocity of the groundwater. In addition to the aqueous diffusion, the transversal dispersion may affect the dissolution rates of pollutants from a DNAPL pool. Equilibrium solubilties of PAH from coal tar were measured in dialysis batch experiments and follow Raoult's law. The measurement of dissolution rates of PAH from coal tar pools were conducted in tank experiments with defined pool dimensions. By variation of the flow velocity transversal dispersivities were determined for various grain sizes. Further studies were carried out to investigate the solubilization of PAH by the application of surfactants, and to determine whether the dissolution rates can be increased by increasing the equilibrium concentrations of PAH.

TESTING THE VALIDITY OF THE HSSM KOPT MODEL BY SIMPLE LABORATORY COLUMN EXPERIMENTS USING DIFFERENTLY STRUCTURED SOILS

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Laboratory infiltration column experiments were made to expand our experimental data base. The experiments were performed with four type of soil samples (sand, loess and two aggregated subsoils) using four type of liquids (distilled water, isooctane, cyclohexane and paraffin oil).

The specific objectives of this research were: (1) to find easy experimental techniques to simulate spills in differently structured unsaturated media, (2) to perform spill simulations in one-dimensional column systems and generate a data base on the vertical movement of NAPLs in the unsaturated zone, (3) to test the HSSM KOPT model against the experimental results, (4) to evaluate the effect of the degree of aggregation on the simulation results.

There was established that quantitative agreement of HSSM KOPT simulations with the experimental results depend on the accuracy of the input parameters. The results of the simulations were depended primarily on the saturated hydraulic conductivity. The estimation of this parameter is based on the result of our former measurements. The results show, that - as far as NAPLs are concerned - in structured soils the degree of aggregation is the factor which fundamentally determined the hydraulic conductivity. Therefore, in the case of structured samples, some modifications were made on the settings of the model, according to our earlier investigations, to use the real hydraulic conductivity values during the simulation.

VACUUM INDUCED FLOW PROCESSES IN HORIZONTAL WELLS

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For non miscible contaminants lighter than water remedial efficiency can be increased by simultaneously removing contaminated water and soil air in horizontal wells. Further an extraction from a defined capture zone is yearned in remedial activities, through which water treatment efficiency is augmented. In order to asses vacuum induced flow processes in horizontal wells, two-phase (air-water) experiments were conducted in a sand filled, 7 m long flume at various vacuum pressures and considered different water table distances. The investigations revealed that the water extraction rate can be controlled accurately by adjusting the applied vacuum through the airblower. The extraction occurs at the capillary fringe and is so limited to the topmost zone, in which contaminant concentrations are usually high. If the downstream water table is lowered, the groundwater extraction can be limited only to the upstream source zone. The contribution will focus on the experimental set-up, parameter estimation and 2-phase numerical simulations of the observed laboratory experiments.

DISSOLUTION OF RESIDUAL NAPL IN WATER SATURATED POROUS MEDIA : MODEL EXPERIMENTS AND NUMERICAL SIMULATIONS

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The dissolution of pure organic chemicals is carried in a cylindrical column. The column is filled with a calibrated silica sand and saturated with clean water. NAPL (toluene or TCE) is then injected until irreducible water saturation is achieved. Afterwards water is injected at constant flow rate to displace NAPL until residual saturation. At this point dissolution starts and several hundreds of pore volumes of clean water are required to completely dissolve NAPL. During experiments, NAPL saturation fields are obtained by the gamma-ray attenuation technique and effluent concentration is measured by gas chromatography. A numerical model based on the macroscopic scale mass balance equations is used to simulate experiments. The model takes into account for convection, dispersion and mass exchange between NAPL and water. The volumetric mass transfer coefficient used in the model, is calculated as a function of NAPL saturation and flow velocity in periodic unit cells. The comparison between experimental and numerical data is satisfactory as the model predicts well the total dissolution time. However, small differences between numerical and experimental saturation fields are observed. Some possible explanations such as heterogeneities and sorption are suggested.

SEQUENTIAL LEACHING OF ORGANICS FROM SOILS: COMPARISON OF LEACHING FLUIDS AND KINETIC INVESTIGATIONS

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In recent years the assessment of organic soil contamination focuses on that portion which is available to microbial and transport processes, rather than on the total contaminant contents. However, the methods employed for determining the available portion differ widely and the results obtained are, thus, not comparable. The modes of action of the eluents and the factors influencing it are left to speculation.
We have investigated the effects of different aqueous eluents towards total organic matter leaching from soil in column experiments. The leaching capacity of the eluents can be explained by their ability to interact with calcium complexes. This is confirmed by the DOM characteristics (molecular weight, ionic character) and the inorganic constituents of the leachates. The leaching kinetics allow to distinguish between spontaneous leaching of readily available organics and diffusion controlled leaching of organic substances from inner spheres of the soil.
We propose a sequential leaching procedure with four eluents of increasing leaching capacity towards the soil organic matter. Since contaminant desorption will be affected by the same factors governing total organic matter desorption, this procedure will allow to differentiate leachable soil contaminants according to their strength of association with the soil matrix. The potential of this sequential leaching procedure will be illustrated by its application onto sewage farm soils, contamined with wastewater constituents over one century.

ASSESSMENT AND UNDERSTANDING OF NATURAL ATTENUATION IN A BTEX AND PAH'S PLUME

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Typical organic contaminants related to a manufactured gas plant are aromatic hydrocarbons, phenols and heterocyclic aromatic compounds. In the framework of a current research program (funded by the German Research Foundation) the fate of BTEX and PAHs have been investigated in a Quaternary porous aquifer below a manufactured gas plant in Southwest Germany. Goals of the investigations are (i) the natural occurring biodegradation, (ii) the partitioning of contaminants between immobile constituents exhibiting a strong reaction with the aquifer material and the mobile aqueous and gaseous phase. The specific geochemical characteristics of the aquifer control the distribution and fate of the organic contaminants in the plume. Important factors are the occurrence of different electron acceptor systems such as oxygen, iron and manganese species, nitrate and sulfate which may be used by the microbial community to oxidize anthropogenic pollutants as well as natural organic carbon. The metabolisation of the contaminants results in a characteristic change of the aquifer chemistry (e.g. DOC, pH, eH, CO_2, conductivity). The microbial activity leads to prevailing anoxic conditions in parts of the aquifer. In these anoxic zones some aerobically degradable aromatic pollutants become more persistant to microbial degradation. The natural attenuation of pollutants in plume is dependent on the type of electron acceptor available for the sub surface microbiology and the partitioning of the contaminats between the different phases present in the aquifer.

EXPERIMENTAL AND NUMERICAL INVESTIGATION OF TWO-PHASE FLOW IN FRACTURED POROUS MEDIA

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Laboratory experiments have been carried out in homogeneous and fractured porous media. Through capillary pressure measurements and transient displacement experiments the hydraulic properties of the homogeneous matrix material were found. Single- and two-phase flow experiments were subsequently conducted in two-dimensional systems ($L = 30$ cm, $W = 20$ cm, $H = 2$ cm) with one fracture transecting the matrix. From solute transport experiments with the single fractured systems information about the fracture geometry was derived. This information was utilized in two-phase oil-water experiments. Measurements of oil and water pressures, using hydrophobic and hydrophilic tensiometer, at different locations in the matrix together with measurements of the average phase saturation within the cell served as the basis for testing the ability of numerical simulators to predict immiscible flow in fractured porous media.

NUMERICAL MODELLING OF MULTIPHASE FLOW IN POROUS MEDIA AND FRACTURED ROCK - CASE STUDIES

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A number of geohydrological problems requires the analysis of multiphase fluid flow in soil and rock, e.g. such as infiltration processes or underground disposal of hazardeous waste. The first part of the contribution is focussed on aspects of the numerical treatment of the equations of multiphase flow. A Newton-Raphson rule is applied to solve the resulting non-linear equations. The discretization in space is realized with the finite element method and implicit schemes are used for discretization in time. Specific time marching and relaxation schemes are introduced, which are controlled by the iteration progress. In particular, these strategies are suited for the modelling of gas-liquid-systems, which show both strong transient and highly non-linear behavior. Secondly, examples of multiphase flow in porous and fractured media are presented, which demonstrate the capabilities of the numerical method. These examples include the infiltration process into soil and the gas-water flow in a fracture.

ANALYSIS OF REACTIVE SOLUTE TRANSPORT IN A HETEROGENEOUS AQUIFER : THE KR AUTHAUSEN FIELD EXPERIMENT

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Theoretical and experimental investigations have shown that spatial variability of hydraulic conductivity causes dispersive spreading of dissolved substances in soils and aquifers. Stochastic theories have been developed which relate this d ispersive sprea ding to statistical properties of the hydraulic conductivity. Most of these stud ies have been dealing with inert substances. Less information is available conce rning the transport of reactive solute transport in heterogeneous soils and aqui fer. In this pr esentation we report on results of a natural gradient tracer experiment using so lutes undergoing nonlinear sorption. The objective of these experiments is to ex amine the influence of spatial variability in both the hydraulic conductivity an d sorption para meters in a heterogeneous aquifer. Combined with the presentation and interpreta tion of experimental data, results of 3D massively parallel simulations of solu te transport undergoing Freundlich sorption in heterogeneous a! ! quifers will be presented.

VALIDATING TWO CRITERIA FOR WETTING FRONT INSTABILITY IN POROUS MEDIA

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Preferential fingering flow that carries high velocity streams of one fluid into another in porous media causes practical difficulties in modelling transport processes involving petroleum as well as water and contaminants in porous media. Two dimensional experiments of water infiltration into air saturated porous media were carried out to verify two theoretical criteria for wetting front instability (the Saffman-Taylor/Chouke's linear instability criterion and Raats/Philip's piston flow criterion). The experiments were especially designed to include four destabilising factors to the wetting front: (a) increase in gauge air pressure ahead of the wetting front, (b) soil layering, (c) infiltration into water repellent media, and (d) air entry from the soil surface. Air-confined and open-bottom column experiments were conducted using water-wet sands, loam and water repellent sands under ponding and negative surface water heads. The results agreed with predictions by the Saffman-Taylor/Chouke's criterion. However, the Raats/Philip's criterion, although valid for sand and homogeneous loam material, failed to predict fingering flow in layered materials with a fine medium overlying a coarse one.

DEVELOPMENT OF THE MULTIPHASE FLOW AND TRANSPORT MODEL TRACE1 AND ITS APPLICATION TO ORGANICS MIGRATION IN A CHALK UNSATURATED ZONE

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A component of the groundwater flow and contaminant transport modelling system TRACE (Tool for Regional Assessment of Contaminated (subsurface) Environments), TRACE1 is a one dimensional numerical model of multiphase flow and transport in the saturated and unsaturated zones. A multi-permeability approach allows for the consideration of fissure, joint and matrix components. Each continuum has its own physical and chemical properties determining the characteristics of the migration of organic contaminants within that continuum. Inter-continua flow and transport transfer terms are based on quasi-steady state relationships. In addition to simulating the bulk flow of each phase (i.e. aqueous, nonaqueous and gaseous), the model includes the transport and transformation processes of advection, dispersion, inter-phase transfer, sorption and biodegradation. The model may be used independently, or to provide input boundary conditions to the three dimensional saturated flow and transport components. Application of the model is illustrated for the migration of organic contaminants in the unsaturated zone of the UK Chalk.

HS5 Flow and transport in unsaturated soils

05 Colloids and colloid-assisted contaminant transport in soils

Convener: Totsche, K.-U.

A COMPARISON OF FACTORS CONTROLLING COLLOIDAL TRANSPORT IN KARST AND POROUS AQUIFERS

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Small particles are considered as colloids when their size allow a transport over a long distance in a given groundwater flow. Three key factors control colloidal transport: (i) characteristics of the flow, (ii) colloid size and (iii) interactions between colloids and rock matrix. Karst aquifers are characterised by a network of mm to meter size diameter conduits draining low permeability (10^{-7} to 10^{-9} m/s) limestone blocks. High water velocity in the drains allows particles bigger than 1 μm to be transported over long distances. With reduced rock-colloid interactions, sedimentation and aggregation are the most influential processes on particle size distribution. To determine their effects, modelling of the flow in complex drain geometries is necessary. In porous media, parameters of flow equations can be determined using inert tracers, even for some heterogeneous conditions. Knowledge of colloid size and porous matrix properties should allow the modelling of colloidal retention using filtration theory. In most instances the predicted values need to be adjusted to measured values. The matrix attaching and releasing of colloids is interpreted as the interaction between charged surfaces using double layer or DLVO theory. The actual interactions are difficult to model due to the medium heterogeneity. The flow conditions in karst and porous media are so different that they lead to distinct physical factors controlling colloidal transport. The surface charge of colloids in natural environments must be understood in detail as it is a key factor for attachment in porous aquifers and aggregation kinetics in karst terrains.

PARTITIONING STUDIES OF ANTHRACENE ON SILICAGEL WITH DIFFERENT CATIONIC SURFACTANT COVERAGE

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The attraction between mineral oxides and hydrophobic organic compounds can be enhanced by surfactant coverage. This process, often termed "adsolubilization", is important for surfactant based environmental technologies, such as in-situ remediation of polluted sites. The distribution ratio (K_d) of anthracene between aqueous solution and silicagel was investigated with respect to the degree and kind of surface coverage with hexadecyl-trimethyl-ammonium-bromide. Different types of surface coverages were inferred from the shape of the surfactant adsorption isothermes as a function of pH and electrolyte concentration. The maximum quantity of monomeric adsorbed surfactant molecules and the type of surface related surfactant aggregates depended on the ionic strength and pH of the solution. These two aspects change the dependency of the K_d on the surfactant coverage. The limitations of using a carbon normalized partition coefficient (K_{oc}) will be discussed.

EVALUATION OF COLLOID-MEDIATED PESTICIDE TRANSPORT: 2. EXPERIMENTS IN UNDISTURBED SUBSOIL

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Transport of strongly adsorbing (SAPs) pesticides through soil may be enhanced in the presence of colloids. The presence of SAPs in shallow or deep groundwater has been attributed to such colloid-mediated transport mechanisms. In the present study we examined leaching of the inert tracer bromide and the pesticide prochloraz through 12 undisturbed soil columns of sandy loam subsoil (Northern Denmark). Steady-state leaching experiments were carried out on soil columns with or without an external top layer of organic matter using two different solutions of a tracer pulse: (1) pesticide in solution, and (2) pesticide adsorbed onto natural clay colloids. The colloids were obtained through fractionation of top soil. Analysis of the bromide breakthrough curves revealed fast breakthrough and significant tailing. This was attributed to the presence of macropores, as was further demonstrated using brilliant blue dye experiments. When colloids were used in the tracer solution the pesticide mass recovery for the colloid fraction < 0.24 μm was 3.5 times higher compared to the mass recovery for leaching with only pesticide in solution. Breakthrough experiments using the external organic layer revealed that addition of pesticides adsorbed onto colloids showed a noticeable pesticide peak in the outflow, a phenomenon which was not present in the case where pesticides in solution were added. This supports the hypothesis that the higher mass recovery for the fraction < 0.24 μm observed in soil without organic layer most likely is due to pesticides adsorbed onto clay colloids. The results suggest that under conditions of colloid-mediated transport structured soil may be more susceptible to pesticide leaching.

THE GENESIS AND TRANSFORMATION OF COMPLEX ORGANO-MINERAL COLLOIDS IN A DRAINED PEATLAND AREA

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The spatial evolution of colloids from peat bogs to the river, was studied in a karstic watershed (Jura Mountains, Switzerland) by bulk chemistry and microscopy.
Raw waters (peat bog pore waters, waters from artificial drains and river water) were fractionated using filtration and dialysis and analysed using ICP, IC, Colorimetry, TOC, UV-Vis, TEM-EDS, STEM-EDS and EF-TEM. Microscopic analyses correlate bulk sample results but highlight interesting features at the level of the individual colloids. In the peat, TEM-EDS shows a large predominance of Ca precipitated onto organic mater, while bulk chemical analyses show that [Fe^{2+}] decreases from the peat to the river as a function of pH and [O_2]. In the river, STEM-EDS reveals Fe-Ca-rich globular colloids with a core of carbon determined by EF-TEM.
We may thus postulate that, Fe-rich entities found in the river, originate from the oxidation of Fe^{2+} on the surface of Ca-rich organic colloids, as they are transported from the peat to the river by drains.

COUPLED TRANSPORT OF PAH AND SURFACTANTS IN NATURAL AQUIFER MATERIAL

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Surfactants assemble in aqueous solution at mineral surfaces and form micelles above the critical micelle concentration (CMC) due to their physico-chemical properties. Hydrophobic organic compounds such as polycyclic aromatic hydrocarbons (PAH) have a high affinity to the adsorbed surfactant layers (monomers, hemimicelles and admicelles) and the micelles in the mobile aqueous phase. The transport of the PAH is controlled by the concentration of the surfactant and the partition coefficients. K_{adm} and K_{mic} of the PAH between water and admicelles (adsolubilization) and water and micelles (solubilization), respectively. These partition coefficients were measured in laboratory batch and column experiments using phenanthrene as a chemical probe for the PAH, non-ionic and anionic surfactants, natural aquifer sand and its petrographic subcomponents. The sorption of the surfactant can be described by a linear isotherm for concentrations up to the CMC and a sorption- maximum at and above the CMC, which depends on the grain size and the surface properties. K_{adm} was found to be higher than K_{mic}. Both depend on the surfactant's properties. In the column experiments using fluorescence online detection an enhanced retardation of the PAH was observed up to surfactant concentrations above the CMC followed by a facilitated transport only well above the CMC. The retardation factors can be predicted reasonably well calculating a mass balance with the coefficients determined in the batch-systems.

WATER SOLUBILITY ENHANCEMENT OF BENZO(A)PYRENE AND 2,2',5,5'-TETRACHLORBIPHENYL BY DISSOLVED ORGANIC MATTER (DOM)

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Is is generally assumed that hydrophobic organic compounds such as polycyclic aromatic hydrocarbons (PAH) and polychlorinated biphenyls (PCB) with very high K_d values are virtually immobile in soil. However, the transport of PAH and PCB adsorbed to dissolved organic matter can occur. Significant solubility enhancements of these contaminants by DOM may be described in terms of a partition like interaction of the solutes with different DOM species. In laboratory studies, the influence of solution chemistry on the binding of benzo(a)pyrene (BaP) and 2,2'5,5'-tetrachlorobiphenyl (PCB 52) by DOM was examined by using a batch technique where sorption coefficients of DOM where determined by reduced surface sorption of radiolabelled compounds to a hydrophilic surface. DOM originating from a former sewage farm soil and an acidic and a limed forest A_{eh}-horizon in comparison with an Aldrich humic acid were used for the experiments. The results demonstrate that the apparent solute solubilities of BaP are more influenced by DOM-origin than by DOM-concentration. The sorption of BaP increased with low ionic strength and increasing pH. However, DOM hardly has an effect on the sorption of PCB 52. Characterization of the DOM-solutions suggest that the presence of aromatic moities, carboxylic acid groups as well as hydrophobicity and colloidal phases (molecular size) may have a large influence on sorption processes.

MODELLING SURFACTANT INFLUENCED PAH MIGRATION

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Within the framework of a comprehensive investigation concerning the use of surfactants to enhance the remediation of PAH contaminations in the subsurface, a multicomponent transport model was developed to study the processes (interactions) taking place when surfactants and PAH migrate through porous media as solutes. Based on a close co-operation with the laboratory investigations during model development only those processes that could have been identified within lab experiments have been implemented in the model: (i) surfactant-micellization, (ii) surfactant sorption (formation of hemi- and admicelles), (iii) intra-particle diffusion of PAH, (iv) PAH sorption on hemi- or into admicelles, (v) solution of PAH within micelles. Furthermore process-oriented descriptions are used to guarantee that only measurable parameters are needed as model input. In a first step column experiments (see J. Danzer, 'Coupled transport of PAH and surfactants in natural aquifer material', this session) have been simulated by pure forward modelling in order to validate the processes implemented in the model. It was found that the model is able to reproduce the experimental results very well. Furthermore several parameter studies were conducted to determine the demands on a surfactant in view of an application within a remediation.

IN-SITU MOBILIZED COLLOIDS AND THEIR ROLE IN FACILITATED CONTAMINANT TRANSPORT.

D. Grolimund, M. Borkovec, and H. Sticher (Swiss Federal Institute of Technology, ETH-ITO, Zurich)

In soils and subsurface aquifers, colloidal particles are suspected to contribute to the mobility of pollutants by acting as mobile carriers. Despite the possible importance of this additional transport mechanism, experimental evidence is rare; especially in the case when pollutant transport is facilitated by in-situ mobilized colloids. In this paper we present the results of experiments on the in-situ mobilization of soil-borne colloids in either uncontaminated or contaminated soil columns. We show that substantial amounts of a contaminant (Pb^{2+}) can be transported in association with in-situ mobilized colloidal particles. Under certain conditions, which are realistic in field situations, such colloid facilitated transport is shown to be the dominant transport pathway. The colloidal bound contaminant fraction in solution can exceed the dissolved fraction by several orders of magnitude. Mobilized inorganic particles are responsible for the increased total contaminant concentrations. The influence of important system variables such as flow velocity, reattachment or contaminant desorption on the colloid facilitated transport will be discussed.
The observed colloid facilitated transport mechanism will be discussed in terms of ion exchange and colloid transport as well its possible implications in the field.

ORGANIC COLLOIDS IN FOREST SOILS: 1. BIOCHEMICAL MOBILIZATION IN THE FOREST FLOOR

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Colloid-assisted contaminant transport in soils strongly depends on the concentration, the chemical composition and the charge characteristics of the carrier. Organic colloids are produced in significant amounts in the forest canopy and the forest floor. Besides pure chemical dissolution equilibria biotic processes comprise to the mobilization of organic colloids. A concert of destructive and non-destructive analytical methods applied on solid and colloidal organic matter obtained in the forest floor was used to assess the formation and mobilization pathways of organic colloids. The studies suggested that a major part of the organic solutes are lignocellulose-degradation products being strongly microbially altered in the course of ligninolysis. The release of lignin-derived moieties into the soil solution is directly controlled by their degree of biooxidation. Microbes contribute also directly to the organic solutes through the release of microbial metabolites. There are indications that the microbially-controlled production of organic colloids in the forest floor is highly vulnerable to short- and long-term changes in the soil environment.

INFLUENCE OF DOM QUALITY, DOM QUANTITY AND WATER REGIME ON TRANSPORT OF SELECTED HEAVY METALS

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In sandy soils with neglectable clay content soil organic matter plays the mayor role for the sorption of heavy metals. Solid phase and water insoluble organic matter immobilizes the heavy metals, while low molecular soluble organic matter (DOM) as a sorbent can enhance the mobility of some metals. Important influencing factors for the solution and transport enhancement of heavy metals by DOM are DOM-concentrations and DOM-quality. Both parameters show a distinct seasonal and spatial variability in the soil solution in response to precipitation and water regime.
These processes are investigated at a field station on a former sewage farm in Berlin (Germany) since 1993. The spatial variability at the field site is causing the strong heterogeneity of the humic top soil and water regime. These differences were reflected in the large variability of DOM- and heavy metal concentration in the soil solution. In comparison to an operating sewage farm, DOM-concentrations in the soil solution were greatly increased. A concomitant heavy metal mobilization is observed and is clearly attributable to DOM enhanced transport for Cu.

NUMERICAL SIMULATION OF CARRIER FACILITATED CONTAMINANT TRANSPORT IN SOILS

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Contaminants with very low water solubilities play an important role in risk assessment of dangerous wastes and development of soil remediation. The mobility of such hydrophobic substances can be strongly affected by the existence of carriers, which can adsorb the contaminant and thereby enhance or reduce its velocity. Our development is based on a model, in which all the carrier's influence on the contaminant transport is contained in an effective adsorption isotherm, depending on the carrier concentration and thereby also on space and time. The numerical simulation of the spreading of these contaminants requires the solution of the saturated-unsaturated water flow problem and reactive transport equations for all involved components, coupled by the contaminant's sorption to the carrier. The model equations are in general nonlinear, degenerate and their solutions exhibit sharp fronts. The numerical simulation therefore requires the use of robust numerical algorithms. In addition the developped software is based on efficient numerical techniques to make its computation possible on PC's.

MOBILIZATION AND TRANSPORT OF COLLOIDS IN A MACROPOROUS SOIL

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Colloid-mediated transport has been suggested to be an important process in the leaching of adsorbed contaminants. Colloid mobilization and transport was quantified in intact soil columns (18.3 cm diameter, 20 cm length) of a sandy loam soil. In experiment 1, the mobilization of natural colloids and subsequently breakthrough of illite suspensions was measured. Irrigation intensities of either 11 or 30 mm per hour were used on samples from 2-22 cm or 42-62 cm depth. In experiment 2 the effect of ionic strength and pH were investigated. The cumulative amount of mobilized particles as a function of cumulative water outflow was unaffected by irrigation intensity, while the mass recovery of an illite suspension was significantly larger at the high irrigation intensity. The mean particle diameter in the effluent decreased over time during both the leaching of naturally occurring particles and the illite suspension. Presence of a continuous macropore system and the kinetics of the detachment of particles from the macropore walls are the main conditions controlling the detachment and further transport of particles. Lower ionic strength and higher pH increases the mobilization of colloids. However, the response was dependent on the degree of physical nonequilibrium.

EVALUATION OF COLLOID-MEDIATED PESTICIDE TRANSPORT. 1. EXPERIMENTS IN UNDISTURBED TOPSOIL

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Transport of strongly adsorbing pesticides has been related to heterogeneous transport and colloid mediated transport. These hypotheses were tested with infiltration experiments on 24 undisturbed columns taken from a sandy loam topsoil. The columns were irrigated at a constant rate of 10 mm/hour. Prochloraz, a fungicide, and bromide were applied as a pulse input to the surface. The ionic strength and pH were varied during the experiments, and further, a stopped flow event was included. Finally, infiltration of a color dye (Brilliant Blue) was used to evaluate preferential flowpaths. The amount of pesticide leached varied over more than three orders of magnitudes among the different columns. This variation was caused by, in decreasing order: i/ the extent of physical non-equilibrium in the column, ii/ the solute pH and, iii/ the ionic strength. Raising the pH of the applied solute caused secondary breakthrough peaks of both particles and pesticide, indicating that the pesticide was transported along with mobilized natural colloids.

ORGANIC COLLOIDS IN FOREST SOILS: 2. ABIOTIC IMMOBILIZATION IN THE MINERAL SOIL

K. Kaiser, G. Guggenberger and W. Zech (Lehrstuhl fuer Bodenkunde und Bodengeographie, Universitaet Bayreuth, D-95440 Bayreuth, Germany)

Colloid-assisted contaminant transport in soils strongly depends on the concentration, the chemical composition and the charge of the carrier. These characteristics are strongly altered when organic colloids derived from the forest canopy and the forest floor enters the mineral soil. In contrast to the mobilization process, the interactions with the mineral soil matrix is controlled by abiotic processes, mainly sorption. Field studies and laboratory based sorption experiments combined with destructive and non-destructive analytical methods were used to identify the controls on the colloidal organic matter immobilization during the passage of the mineral soil. The results indicated that the immobilization is mainly due to sorption on Fe and Al hydrous oxides. The degree of binding depends on the amount of sorbents, their initial loading with organic matter, and the chemical features of the organic colloids. The lignin-derived moieties seem to be preferentially removed from the soil solution whereas the microbial products accumulate. Thus, the passage of organic solutes through the mineral soil is a chromatographic process which controls the amount and the chemical characteristics of organic colloids reaching the hydrosphere.

THE MODELING OF SURFACTANT TRANSPORT, SOLUBILIZATION AND MOBILIZATION OF HYDROPHOBIC ORGANIC CONTAMINANTS

P. Knabner and **E. Schneid** (Institute for Applied Mathematics, University of Erlangen, Germany)

Surfactants have a strong influence on the transport of hydrophobic contaminants not only due to solubilization but also by modification of the interfacial properties between phases. The modeling of surfactant enhanced contaminant transport deals with three transport processes which can be coupled by the presence of surfactants. First, the water flux is described by Richards' equation. The capillary pressure saturation relation depends on the surfactant concentration via the interfacial tension. The filtration of surfactants at concentrations above the critical micell concentration can modify the porosity and therefore the permeability. Second, the surfactant transport equation includes sorption phenomena which are caused by an interaction between different isomeres of a surfactant. Additionally, the different sizes of monomer and micellar surfactants may necessitate a dual porosity model for the transport. We assume the third process, the contaminant transport, to have no influence on water flow or surfactant transport because of low concentrations or high viscosity of contaminants. The presence of surfactants causes a variety of sorption processes for the contaminant. We present a mathematical model of coupled water-, surfactant- and contaminant transport. Its numerical simulation supports the development of remediation strategies.

TRANSPORT OF COLLOIDS IN SOILS AND AQUIFERS: IMPORTANCE OF SURFACE CHEMISTRY

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Mobile colloids in soils and groundwater aquifers can act as carriers for strongly sorbing chemicals and may enhance contaminant transport. Field studies suggest that mobile colloids can include clay minerals, oxides or hydroxides of Fe and Al, colloidal silica, organic matter, and biocolloids such as viruses and bacteria. The transport of colloids through porous media strongly depends on the kinetics of colloid deposition and release. Important chemical factors controlling colloid deposition and release kinetics in natural porous media are the charge of matrix and colloid surfaces and electrolyte type and concentration in the solution phase. The surface charge is strongly influenced by solution pH and the presence of specifically adsorbing ions, including organic polyelectrolytes such as humic substances. Surface charge heterogeneities on colloids and matrix surfaces also play an important role. Colloid transport experiments conducted under well-controlled conditions (i.e., column studies) will be presented to discuss some important phenomena, including the dynamics of colloid deposition kinetics with increasing loading of matrix surfaces.

COLLOID-FACILITATED TRANSPORT OF CONTAMINANTS IN GROUNDWATER

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The importance of colloids to the subsurface transport of contaminants depends on both contaminant-colloid interactions and the mobility of the colloids. While a theoretical framework exists for describing colloid formation, stability and transport in model systems, the principal scientific issue that limits prediction is understanding how colloids behave in natural subsurface systems. This talk will review data on the extent of colloid transport in the subsurface with an emphasis on field-scale processes that affect colloid-aquifer interactions. Studies on the mobility of organic colloids (natural organic matter, NOM) in natural systems, and the effect of mobile NOM on the mobilization and transport of transuranic radionuclides will illustrate some of these issues. For example, although laboratory studies document significant binding of NOM to mineral oxides and clay minerals, it will be shown that radionuclides complex with NOM and are co-transported over distances of 100-m with minimal retardation because aquifer surfaces are saturated with respect to binding of groundwater NOM. Research on the fundamental processes should recognize and account for the properties of natural subsurface systems that influence colloid behavior.

DOM-ENHANCED PAH- AND PCB-MOBILIZATION IN CONTAMINATED SOILS UNDER DIFFERENT CHEMICAL CONDITIONS

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In soils and sediments, hydrophobic organic xenobiotics such as polyaromatic hydrocarbons (PAH) and polychlorinated biphenyls (PCB) are strongly sorbed to solid-phase organic matter. But even compounds with very low water solubilities and high Koc-values can be desorbed and mobilized by dissolved organic matter (DOM). This solubility and transport enhancement is dependent on DOM-concentrations and its sorptive capabilities. Both these parameters are influenced by soil and solution chemical properties. In a column study with limed and acidified contaminated sewage farm soils, the mobilization of benzo(a)pyrene (BaP) and 2,2´,5,5´-tetrachlorobiphenyl (PCB 52) was monitored over a period of 14 months with periodical irrigations under usaturated conditions. In the acidified soils, both compounds were initially fixed more strongly than in the control and limed soils. However, after repeated percolations with H_2O, a strong release was observed, with solution concentrations up to 60 µg/l for BaP and 140 µg/l for PCB 52. Similarily, BaP was released during a short period in the limed soils. These effects can be mainly attributed to changes in DOM-composition in response to changes in soil chemistry (pH, Ca-concentrations) which is supported by additional evidence from batch experiments.

Occurence, deposition and remobilisation of Myxobacteria in subsurface Karstsediments

Benjamin Menne, Mühlacker

The myxobacteria are Gram-negative, gliding bacteria with an impressive and unique process of cooperative morphogenesis. The principal habitats of myxo-bacteria are soil, dung and decaying plant material We know quite a lot about their ecology and their distribution . During the last decade the author studied severel hundred of subsurface sediments collected from caves. The occurence and the distribution of the myxobacteria in the samples became examined. Myxococcus fulvus is the absolutely dominant species of myxobacteria in those subsurface sediments.
The quantitative distribution of the organisms was proved as strong dependently on the position of the samples either to the surface or to the karst-water-table. A clear dependence also could be seen by the sedimenttype (texture). Sand was proved to be colonised preferentially. The hydrologic situation and events are responsible for deposition and remobilisation of the cellular colloids, but we also observed strong differences at the species level Physical measurements complete the results It becomes strong dependences of the biotop temperature stated. Also was the formation of ecological races at the species isolated from karstic sediments proved.
The research let recognize the divison of microbiological reaction-zones in the karst.

DISSOLVED ORGANIC MATTER ASSOCIATED PHOSPHORUS TRANSPORT IN ACID SANDY SOILS

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A substantial part of total dissolved phosphorus (TDP) in soil solution can be present as dissolved organic phosphorus (DOP) and/or colloidal phosphorus forms. In order to study the mobility of these phosphorus (P) forms and to estimate their contribution to P leaching losses from soil, a fractionation and determination procedure was developed, defining six operational P fractions. Combining Sephacryl S-100 gel filtration and ^{32}P isotopic techniques, the occurrence of two different types of dissolved organic matter (DOM) associated P compounds was demonstrated. The first type is determined as molybdate reactive P (MRP), but using ultrafiltration, it was shown to be colloidal. Iron (Fe), aluminium (Al) and dissolved organic carbon (DOC) concentrations correlated well with this colloidal P fraction, suggesting it may consist of DOM- Al- (Fe-) P complexes. The second type of compounds corresponds to the DOP fraction, determined after UV photo-oxidation. Adding ^{32}P-orthophosphate to soil solution samples didn't label this fraction, except after incubation of labeled soil. Gel filtration of this fraction, which is hypothesized to contain mainly DOC-P complexes (P esters), clearly showed two distinct molecular weight fractions. DOP content of soil solutions collected up to a depth of 90 cm from some typical podzol profiles in northern Belgium, varied between 7 and 520 $\mu g\ L^{-1}$, corresponding to 5-71% of TDP. Also, 42-83% of MRP was shown to be colloidal in nature.

Transient transport of surfactant in a calcareous and clayey soil

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In the field of soils remediation, many tentatives have been carried out to use surfactants as wasching agents. This use in soil pollution treatment has been largely inspired by works developped in petroleum engineering in the frame of Enhanced Oil Recovery Method. Chemical flooding has been experimented with success even if now there is few fields operated by this technique often presented as too expensive with respect to the present price of oil. One of main problem encountred in the use of surfactant in natural porous media is its consumption by retention into the porous matrix, whatever the nature of surfactant : anionic, cationic or nonionic. In a first section dealing with pure anionic surfactants, we will present a simple theoretical representation of the behaviour of a surfactant in contact with a reactive porous media. We will detail on the one hand the interactions in which is involved the surfactant in solution and on the other hand those it is subject to when in contact with calcareous-clayey sandy soil. In a second part, experiments on the transient transport of mixtures of surfactant used in chemical flooding in porous media will be presented. We will then show how the approach previously developed allows us to interpret and model the phenomena pointed out in these experiments. Finally a large part of our presentation will be devoted to the modelling of interactions of surfactants with clays minerals, soluble minerals and the coupling between ion exchange, dissolution/precipitation and micellisation in solution. For example the retention of anionic surfactant will be described by a set of homogeneous (micellisation, cations exchange on the surface of the micelles) and heterogeneous (effective adsorption, precipitation) reactions. Before concluding, special consideration will be put on the facilited transport of colloids (bacteria and lateces) in the presence of surfactants and/or polymers..

KINETIC STUDIES ON THE DISSOLUTION OF SOIL ORGANIC MATTER

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In this study the kinetics of dissolution of soil organic matter in a sandy forest soil near Berlin were investigated. The soil material was put in a small column and was extracted by a continuous flow of water. The content of DOM in the extract was measured by UV/VIS absorption between 210 and 665 nm. The extractions were carried out with varying flow rates between 0.5 and 2 pore volumes per minute at 5-50°C. The dissolution of DOM under these conditions is controlled kinetically, with an activation energy about twice as high as that of diffusion-controlled reactions in water. At temperatures higher than 30°C and lower than 15°C, the rate of dissolution increases with increasing temperature, while it does not change between 15°C and 30°C. This can be explained by the formation of a gel-like state of soil organic matter between 15°C and 30°C, which makes the diffusion of molecules out of the gel more difficult, and thus controls the formation rate of DOM. Thus, one has to consider the formation of DOM rather from kinetic than from thermodynamic points of view. The results of this investigation show once again the importance of the colloidal state of soil organic matter for the regulation of ecological processes in soil.

EFFECTS OF FLUCTUATING INPUT OF DISSOLVED ORANIC MATTER (DOM) ON SORPTION AND LONG-TERM MOBILITY OF POLYCYCLIC AROMATIC HYDROCARBONS (PAH) IN SOILS

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The role of DOM as a mobile sorbent affecting PAH mobility in soils is well documented. For individual PAH congeners, the extent of DOM-PAH associate formation is both controlled by the formation constant (K_{dom}) and the PAH/DOM concentration ratio. At constant inputs and under the assumptions of a co – transport/ co – sorption scenario, whether associate formation leads to enhanced or reduced PAH-mobility. is solely controlled by the composition of bulk solid. However, under field conditions, DOM discharge to the mineral soil is not constant, but exhibits strong seasonal fluctuations. We therefore included instationary upper boundary conditions for DOM to our numerical simulations of centennial PAH mobility. Results show, that upon these fluctuations, the proportion of DOM – associated and free PAH in soil solution become both time– and depth – variate, thereby also affecting the composite retention of overall PAH. Calculated depth profiles of sorbed PAH, based on different time – variate but mass –i nvariate upper boundary conditions for DOM, therefore show striking differences, too. Our results suggest, that instationary upper boundary conditions affect calculated PAH depth profiles beyond the constituents of bulk solid.

HS5 Flow and transport in unsaturated soils

06 Frozen soils: processes and properties

Convener: Jansson, P.-E.

THE ROLE OF DISSOLVED ORGANIC CARBON ON THE FATE OF XENOBIOTICS IN SOIL-AQUIFER-SYSTEMS

Matthias Schulze, Harry Vereecken, Heinz Wilkes

There is increasing evidence that dissolved organic carbon (DOC) may play a role in the transport of xenobiotics in soils and aquifers. Xenobiotic substances may e. g. show reversible or irreversible interactions with DOC and may be transported as a DOC/xenobiotic complex. The present study aims at a better understanding of these interactions in a more general framework, dealing with the behaviour of pollutants in soil-aquifer systems. The work focuses on the analytical characterisation of DOC and DOC xenobiotic complexes and on column experiments describing the influence of DOC on the transport of selected pollutants. DOC-material obtained from of adsorption on diethylaminoethylcellulose was subjected to different spectroscopic methods for chemical characterisation. We especially used the advantages of Curie point pyrolysis-gas chromatography-mass spectrometry. Experimental investigations on the influence of DOC on the transport behaviour of selected pollutants were performed on undisturbed soil columns sampled from a test site near the Research Centre J=FClich. The affinity of selected model xenobiotics (e. g. acenaphthene, dibenzofuran, 4-chlorodiphenyl) to DOC obtained from peat was determined by batch experiments, and this yielded the basic data for the setting up of the column experiments. The pollutants were applied to the top of the soil columns on which a constant flux of water containing different DOC concentrations was imposed. Major objectives of these experiments is to determine breakthrough curves of the xenobiotics depending on DOC concentrations and to characterise the organic constituents in aqueous effluents by HPLC. These investigations will provide a better understanding of the type of bonding of pollutants to DOC and, therefore, provide new insights in the possible role of DOC as a sink and/or source of xenobiotics in soil aquifer systems. Our future research will focus on the implementation of these results in a mathematical modelling of the transport of organic pollutants in geological systems.

EEFECTS OF MICROBIAL TRANSFORMATION OF ORGANIC MATTER ON SOME PARAMETERS OF SOIL PHYSICAL STATUS

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A development of systems of sustainable land use increasingly requires quantitative data on the relationships between soil physical properties and mineralisable organic matter content. In the present studies, the processes of transformation of organic matter by thermophilic microflora in the unsaturated soils were used to evaluate importance of changes in contents of humus and its constituents for soil physical status. Disturbed samples taken from the profiles of six soils were incubated at 65°C and soil water content of 60% of complete saturation for 6-27 weeks. A decrease in content of mineralisable portion of organic carbon by 1.5-3.5 g kg^{-1} had more or less pronounced effect on parameters of soil physical status. There were differences in microbial stability of humus of loamy sand dernogleyic, loam dernopodzolic, sandy loam podzolic, clayey loam meadow-brown and dark-grey soils, and clayey loam typic chernozem as related to soil genesis and land use system. Humic substances such as humic and fulvic acids, humins showed different contribution to soil water retention, water vapor adsorption, and processes of swelling - shrinkage of native and agricultural soils differing in genesis, texture and composition of mineral solid phase. Based on the results obtained, approaches were proposed to evaluate possible unfavorable consequences of microbial transformation of organic matter for soil physical status.

THERMAL AND HYDROLOGICAL DYNAMICS OF THE ACTIVE LAYER AT A CONTINUOUS PERMAFROST SITE

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The ground thermal and hydrological regime of a site located in the continuous permafrost landscape of Taymyr Peninsula, northern Siberia was studied in 1994 and 1995. The aim was to quantify the seasonal fluxes of water and heat in the active layer from spring thaw to fall freeze-back. Liquid water content was measured in frozen and unfrozen soils using time domain reflectometry (TDR). Liquid water was present in frozen soil at temperatures down to -12 °C and its volumetric fraction increased with temperature before melting occurred. The ground thermal regime during spring thaw and fall freeze-back is dominated by latent heat fluxes that stabilize soil temperatures at 0 °C for extended periods. During the summer, the thermal regime of the saturated active layer may be understood from assuming density driven convection as the mechanism of heat transfer. Convective transfer also appears to be dominating during fall, when large amounts of latent heat are released by freeze-back. The soil heterogeneity strongly impacts hydrological and thermal processes in the active layer. Two direct consequences are the development of preferential flowpaths and preferential freezing of the profile during freeze-back.

MODELLING SOIL FREEZING AND THAWING AND ITS EFFECT ON N2O EMISSIONS FROM AGRICULTURAL SOILS

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The object of this study is the development and test of a simulation model to describe N2O-release from agricultural soils during the winter period. It is the aim to get a better understanding of the underlying processes, which determine the dynamics of the observed N2O-emissions. In a 2-year field study N2O-emissions were monitored using a closed chamber technique. Results show a major portion of the total N2O being released during only a few events with extremely high emission rates. Most of these peaks occured during and after freezing-thawing cycles or rewetting of dry soil. Therefore we put emphasis on modelling the freezing-thawing and drying-rewetting cycles as accurate as possible. An existing nitrogen turnover and transport model was extended by a submodel for soil freezing and water flow in frozen soil. Furthermore the denitrification submodel was extended to consider frost and rewetting effects. Different modelling approaches were tested for their ability to reproduce and predict N2O-emission dynamics over several years. The model comparison suggests that a rather simple N2O production approach is the most adequate to estimate N2O release from agricultural soils during winter.

NITROGEN TRANSFORMATIONS IN AN ALPINE GLEYIC FOREST SOIL SUBJECT TO INCREASED NITROGEN DEPOSITION

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In a Gleysol of an alpine forest site in Alptal, Switzerland, nitrogen transformations are investigated within the NITREX project. The paper presented here aims at studying the relation between microbial N transformation and runoff processes. Both microbial immobilisation of N and the contact time between soil solution and soil matrix could affect the rate of nitrate leaching. Throughfall and soil solution of 5, 10, and 30 cm depth are collected in 10 plots (20 m^2), 5 plots with simulated increased N deposition (+ 30 kg NH_4NO_3-N/ha/a) and 5 plots with ambient deposition (17 kg N/ha/a). Furthermore, we collect the runoff of two forest catchments (1500 m^2), with and without nitrogen addition. Dissolved organic nitrogen (DON) is the major N-species in the soil solution, the proportion increasing with soil depth. The NO_3/Cl ratio decreases characteristically from the throughfall to the Gr-horizon (30 cm depth) indicating losses via denitrification. Redox potentials measurements confirm these findings. In the runoff of the forest catchments the NO_3/Cl ratio as well as conductivity and manganese concentrations are similar to those in the soil solution at 5 cm depth. This points to solute transport by preferential flow and a short contact time between soil solution and soil matrix. Simulation of increased N-deposition increases the nitrate concentrations only in the topsoil and in the runoff, but most added N appears to be retained in the system.

FIELD MEASUREMENTS OF SOLIFLUCTION AND CONCURRENT SOIL WATER AND HEAT DYNAMICS IN THE EASTERN ALPS

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Solifluction movements are closely linked to thermal and hydraulic soil conditions. Local site factors like topography or vegetation cover in combination with meteorological conditions may influence the development and melting of snow cover and ground ice, and therefore control the hydraulic site conditions during thaw consolidation.

We set up a field station in the periglacial altitudinal belt of the Austrian Alps at 2650 m a.s.l., to investigate the dependency of solifluction movements on ground thermal and hydraulic regime in detail. Measurement devices at two sites included solifluction meters for the continuous observation of subsurface soil displacements, heave meters, as well as TDR, tensiometers and thermistors. Data were recorded in high temporal resolution using an automatic logging system.

Preliminary results of winter 1995/96 illustrate, that ground freezing and frost heave continued the whole winter through. Additional ground ice accumulation during early spring snowmelt was observed. Strong solifluction movements were recorded in response to rapid snowmelt and concurrent ground thaw in summer 1996. Different timing of movement onset at both sites may be related to local variations in snow cover height and solar insolation, thus leading to differences in the snowmelt and runoff patterns.

FIELD MEASUREMENT OF DENITRIFICATION IN NITROGEN-AMENDED SOIL

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It is the main goal of our study to analyse the role of the microbial metabolism in the biogeochemical cycle of nitrogen. Denitrification affects the N-cycle since it results in an export of nitrogen gases (mainly N2 and N2O) from the soil to the atmosphere. Our objectives are: -To estimate the effect of increased atmospheric nitrogen depositions on the rate of denitrification. This is done by measuring denitrification on five replicate areas with and without nitrogen addition. -To evaluate denitrification of a large subalpine area with a high spatial heterogenity. Denitrification studies are done on areas with different soil types.-To determine the annual cycle of the emissions of nitrogen gases (N2 and N2O) and to estimate nitrogen gas fluxes for the entire year. Denitrification was measured with the acetylene inhibition method in closed containers in situ as well as in laboratory experiments. Along with denitrification emission measurements, we determined the driving parameters of the process, mainly nitrate concentration, available organic carbon, pH, soil temperature and soil water content. We found a correlation between the soil temperature and the denitrification rate for the unfertilized areas (r2 = 0.7). The reason seems to be a coupled nitrification-denitrification process. The rate of denitrification is higher on the N-fertilized areas only after rain events and at high soil temperatures.

EFFECTS OF WATER TABLE HEIGHT AND WATER-FILLED PORE SPACE ON FLUXES OF N_2O AND NO IN PEATLANDS

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We studied *in situ* N_2O and NO fluxes from peat soils in relation to water table and water-filled pore space, and used peat cores in laboratory experiments to study the changes in N_2O fluxes after changing the water table level. Lowering of water table *in situ* as well as in the peat monoliths from virgin mires increased N_2O fluxes. The increase in the N_2O flux in a nitrogen rich fen started already 12 weeks after the water table draw-down. The rise in water table in peat monoliths taken from fens drained 40-50 years ago decreased the N_2O fluxes immediately. The optimum water-filled pore space for the N_2O and NO emissions varied with time. Due to climate change the ground water tables in the northern hemisphere may lower in the future resulting in higher fluxes of nitrogen oxides from peat soils to the atmosphere. These changes may occur quite soon after lowering of the water table.

NUMERICAL MODELLING OF A GROUND WATER SALT-HEAT TRANSPORT WITH FREEZING

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A numerical model of two-dimensional (profile) salt-heat transport in layered grounds with incomplete saturation is presented. A flow area includes freezers, which action decreases local hydraulic conductivity. River banks with seapage faces are considered as parts of an area boundary. Water flow is governed by Richards equation. salt and heat transports are governed by equations of a convective dispersion type, provided the heat transport equation takes into account a heat conductivity in the ground sceleton. An ice-capacity function which depends on temperature and affects to coefficients of the governing equations is introduced. A finite-difference approximation of the problem is solved by a two-steps iteration method. On the one step the ice-capacity function is calculated. On the other the governing equations at the fixed ice capacity are solved by fast iteration techniques. These techniques are of an incomplete factorization type and especially effective for a case of boundary-value problems with predominating of Neuman conditions at the boundary. As an example of a modelled process a case of the contaminant transport from the earth surface to two rivers is computed. The one or two freezers is added to prevent the rivers from the contamination. The results of the computations show a process of spreading of a concentration and can be used for avaluating of a such ice screens effectiveness. So, in the presented case the freezers can only redistribute the flow but not delay the contamination of the rivers for a long time.

HEAT EXCHANGE AT THE BOUNDARIES BETWEEN FROZEN SOIL, SNOW AND ATMOSPHERE

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In Nordic and alpine regions heat exchange at the soil surface during wintertime is crucially influenced by the overlaying snow cover. Since water redistribution in a freezing soil is strongly linked to the thermal dynamics it is of high importance to accurately describe the heat exchange in models representing scales ranging from plots to regions. In the present study, two winter seasons of contrast characters were investigated with regard to the heat dynamics in the frozen soil-snow-atmosphere system. On four experimental plots (2 x 2 m) in Uppsala (central Sweden) profile measurements of temperature and water content were performed in the soil and the snow together with an extensive micro climate monitoring. The measurements were used together with a one-dimensional heat and water exchange model. For the first winter the sensitivity of the thermal properties of both soil and snow was tested. It was noticed that periods with thin snow covers (only some few centimeters) were less sensitive to the thermal properties, but strongly sensitive to the snow depth and the degree of snow patchiness. The conclusions from this paper suggest that studies of heat exchange processes during winter conditions have to be focused on regions where the snow cover is shifting remarkably within one season or from year to year.

LONG-TERM CORRELATION STRUCTURE BETWEEN CLIMATE, SNOW, SOIL FROST, AND RUNOFF DYNAMICS

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A wintertime subalpine forest exhibits a complex structure of coupled thermal and hydraulic processes with regard to the snow, soil frost and runoff dynamics. Hence, predicting possible changes of these processes caused by climate change is a difficult undertaking. Additional uncertainties arise from the fact that the climate, and even more the weather, is highly variable. A measured weather record covers usually only a limited time period which can be seen as one of many possible realisations.

To overcome these problems a numerical water and energy balance model was calibrated with two-years measurements obtained at small plots within a subalpine forest in Switzerland. The model was subsequently used to simulate climate change impacts for a 80-year period. The model was driven by different realisations of the weather that were produced by a stochastic weather generator using monthly means and variances of measured daily values. Two points with respect to the modelled snow, soil frost, and runoff dynamics will be discussed: (1) the correlation structure between some selected variables representing either yearly accumulated or yearly maximum daily values, and (2) the impact of the different weather realisations to the ecosystem's response.

HS6 Stomatal and canopy resistances in mathematical modelling of SVAT systems

Convener: Matejka, F.
Co-Conveners: Lindroth, A.; Novak, V.

USE OF STOMATAL RESISTANCE: THEORY AND PRACTICE

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As a result of climate change of past decades, the average air temperature increases i 0.3°C every 10 years on the area of the Carpathian basin (Hungary). The temperatu increase is associated with precipitation decrease, the size of alteration is at about 10% in yearly sum of rainfall. Decreasing amount of acceptable water in the soil called th attention of researchers on methodology how to investigate correctly the actual wat status of plants in the plant-atmosphere continuoum. The theory of diffusive resistanc in transpiration determination, is well documented earlier. There is no debate about th primary importance of knowing the exact mean value of stomatal resistance, but hug amount of books and articles deal with arising problems how and where to measure in field conditions. Our purpose was two-fold. first is to determine the likely place (average stomatal resistance of a given plant; and how can it approach with the lea amount of measurements. Field study was carried out at Keszthely (Hungary) both i lysimeter and at natural rainfall. Distribution of resistances within leaves and differe plant levels was measured, and finally a simple formula to determine of it's mean valu is suggested. To verify our resistance data the Crop Micrometeorological Simulatic Model (CMSM) in original form developed by Goudriaan (1977) and modified by Che Jialin (1984) was used. In our investigation the Chen Jialin version is more suitabl because it is easier to handle and works on PC as well. Finally our second aim, th possible usage of stomatal resistances in different case studies will be shown as well.

LABORATORY AND MATHEMATICAL MODELLING OF THE PROCESSES OF MASS TRANSFER IN THE SYSTEM "SOIL-PLANT-ATMOSPHERE"

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The energy- and mass transfer processes in the "soil-plant-air" (SPA) system determine in great degree agrocenosis functioning and agricultural crops formation. Theoretical and experimental study of these processes are rather difficult, since their intensity and characteristics depend on the motion of energy- and mass carriers. Carrying out natural full factorical experiments, based on theoretical investigations, is laborious and practically non-reproducable because of sporadic character of the weather conditions. Laboratory physical methods of simulating energy- and mass transfer processes in SPA systems allow to repeat experiments many times with high degree of reproduction and visuality. Such methods give the possibility to veryficate and identificate mathematical models, to obtain for their construction a priory information on whirewinds formation, regular structures existance, kinds of motion, space arrangement of boundaries of media and motion bifurcal values of parameters, determining the enrgy-mass current structure. The report also concerns the problems of applications of the hydraulic analogy, based on MHD effects generation in water solution electrocycles, for purposes of the simulation in wind interaction process in canopy. The report contains the description of the mathematical model, numeric analysis, the technique of the laboratory experiment and physical simulation results.

APPROACHES TO MODELLING THE BEHAVIOUR OF TRITIATED WATER IN CROPS.

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Tritium in the form of tritiated water (HTO) is released by nuclear installations routinely as well as during accidents. Tritium behaviour in vegetation is very different from that of most other radionuclides and tritiated water may not always follow the flux of water in the plant canopy-atmosphere continuum. The controlling step for both uptake and loss of HTO is believed to be flux through stomata, and thus modelling of canopy processes is of considerable importance in this context, and will be of general benefit for the development of SVAT models. This work is aimed at providing robust parameters for the UK MAFF STAR-H3 model [3]. A major difference between STAR-H3 and a major German model, UFOTRI[2], is that the mechanism of plant-atmosphere exchange is treated using an empirical rate constant in the former while in the latter is described according to the model of Belot [1], with temperature, stomatal resistance and boundary layer resistance determining the uptake and loss of HTO in the vegetation. HTO deposition from air to surfaces has been modelled in two ways either by use of a deposition velocity (Vg) or by use of an exchange velocity. Our validation study of STAR-H3 indicates that the loss of HTO from crop foliage is better described by a double exponential decay, rather than the default single exponential. The advantage of the Vg approach is that values for the deposition velocity and the re-emission rate can be chosen independently unlike the exchange velocity method.

Scaling up of boundary layer conductance from leaf to canopy for a shrub and tussock grass in a semi arid environment

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Many measurements are made at the leaf level, whereas information is usually required at the canopy, stand or regional scale. Consequently the methodology for converting these measurements needs to be developed for a number of different situations. Experimental and theoretical work usually focuses on uniform and extensive canopies, however many areas of the world do not conform to these conditions. In this paper we present the results of an experiment that evaluated the scaling of information from leaves to canopies for a leguminous shrub (Retama sphaerocarpa) and a tussock grass (Stipa tenacissima) in AlmerEDa, South East of Spain. Canopy boundary layer conductance was calculated in the field by measuring the evaporation from artificially wet canopies. R. sphaerocarpa has cylindrical cladodes and an open canopy and S. tenacissima has a dense canopy and leaves that form cylinders by rolling during periods of water stress. Values of leaf boundary layer conductance obtained with cylindrical heated leaf replicas were compared to values of total canopy boundary layer conductance measured the rate of drying of a wet canopy. The results from the current study emphasise the importance of internal shelter effects. The interaction between leaves in Stipa, i.e. the sheltering of each other, produce a lower leaf boundary layer conductance than found for the same wind speed in R. sphaerocarpa. Our results showed that for R. sphaerocarpa the interaction between leaves was not significant enabling the simple extrapolation from a leaf to the whole canopy with the use of leaf area. However this was not possible within dense canopies such as S. tenacissima emphasising the need to develop more robust methods of scaling in these types of canopies.

STOMATAL BEHAVIOUR AND GAS EXCHANGE OF SEDGES (*CAREX* SPEC.) FROM SITES WITH DIFFERENT SOIL MOISTURE REGIMES

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Sedges of the genus *Carex* (Cyperaceae) play an important part in different vegetation types from wet to dry sites in the temperate zones nearly all over the world. For this, knowledge of gas exchange and stomata behaviour of sedges is significant for understanding the exchange of water vapour and carbon dioxide between vegetation and atmosphere. To study gas exchange of *Carex* species several sedges were cultivated under semicontrolled natural conditions and different soil moisture regimes in large pots in an experimental site at the Botanical Garden Düsseldorf (Germany). H_2O and CO_2 gas exchange, leaf conductances and microclimatic parameters were measured porometrically during the vegetation period. Patterns of dependence of leaf gas exchange on microclimatic conditions were worked out for different species and culture regimes. Regression equations were calculated relating leaf conductances with microclimatic parameters. Resulting mathematical models of leaf conductance and gas exchange of *Carex* species will be shown and the differences in photosynthesis, transpiration and stomata behaviour of sedges from various habitats will be pointed out.

IMPORTANCE OF STOMATAL CONDUCTANCE IN MODELLING REGIONAL DAILY AND YEARLY EVAPOTRANSPIRATION AND NET PRIMARY PRODUCTIVITY OF BOREAL FORESTS

Jing Chen, Jane Liu and Josef Cihlar, Canada Centre for Remote Sensing. Hank A. Margolis and Qing-Lai Dang, University of Laval,

In this paper, we will provide a summary of recent findings of the BOReal Ecosystem-Atmosphere Study on stomatal conductance of boreal forests. The BOREAS region in Saskatchewan and Manitoba of Canada is characterized by frequent dry spells during the growing season. During BOREAS intensive field campaigns in 1994 and 1996, it has been found that the stomatal response at the branch level to environmental stresses especially the atmospheric humidity deficit was strong in both jack pine (Pinus banksina) and black spruce (Picea mariana) forests. This finding has implications on regional radiative energy partitioning and weather prediction. In this study, we demonstrate the importance of this finding on daily and yearly regional evapotranspiration and net primary productivity estimates using the Boreal Ecosystems Productivity Simulator (BEPS). BEPS uses remote sensing inputs of leaf area index and land cover type, and soil and daily meteorological data to simulate the processes of photosynthesis, respiration and evapotranspiration at the canopy level.

THE RESPONSE OF CANOPY RESISTANCES OF FIELD CROPS TO EXTERNAL FACTORS

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The objective of this contribution is to determine and analyse canopy resistance response functions using long-term time series of experimental data for winter wheat and maize canopies. The winter wheat grew on carbonate chernozem on an experimental field near Bratislava. The leaf water potential and leaf stomatal resistances were measured in five consecutive years. The data on maize were obtained at an agricultural site near Trnava in 1981 and 1982. The soil type was a chernozem on loess substrate. The evaporative surface was created by maize canopy with the density of 7 plants per square metre. The canopy resistances were calculated from the Penman-Monteith equation. Using these experimental data, the sensitivity of canopy resistance to changes in soil moisture and atmospherical factors were analysed and corresponding response functions were determined.

THE HUMIDITY RESPONSE OF STOMATA

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The aperture of stomatal pores of most plants is quite sensitive to changes in the water vapour pressure difference (VPD) between the internal air space and the external surface of leaves. The resulting effect on leaf conductance needs to be taken into account when modelling water transfer between vegetation and atmosphere, particularly in stands that are closely coupled to the atmosphere (e.g. forests). The effect may be so strong that transpiration rate *decreases* while air humidity is falling.
The steepness and shape of the relationship between conductance and VPD are highly variable. As a result, the structure of the mathematical expressions used to describe the response varies widely between studies, and comparisons of the sensitivity of conductance to changes in VPD observed in different species and under different experimental conditions are difficult.
I will present results of a re-analysis of published VPD-responses using a unified mathematical model and discuss the (hypothetical) physiological mechanisms underlying the VPD-response. Values of parameters obtained from least-squares regression analysis will be classified according to functional plant types with a view to improve the basis for modelling transpiration from different types of vegetation.

PARTITIONING OF EVAPORATION MEASUREMENTS OVER A MILLET CROP IN BURKINA FASO

M.R. Lund (Institute of Geography, University of Copenhagen, Oestervoldgade 10, 1350 Cph K, Denmark)

Facing the problems of using evaporation models developed for homogenously vegetated surfaces in sparsely vegetated ones, modelling of evaporation from the latter environment have received more attention over the last decade.
During the growth season 1996 evaporation measurements in a sparsely covered millet field in northern Burkina Faso were conducted using the eddy correlation technic and sap flow measurements as references for modelling the partitioning of evaporation between plants and bare soil. Additional measurements of standard climatological parameters were collected as well as measurements in the vegetation stand such as LAI and stomatal conductance. Results from selected days which indicate the large variation in the partitioning are presented. As the partition of evaporation in sparsely vegetated environments vary dramatically between plant- and bare soil contribution it is important to develop methods which can model the components individually. Preliminary results on the identification of and modelling with parameters that may describe the partitioning is presented.

CANOPY RESISTANCE ESTIMATION METHOD TO CALCULATE TRANSPIRATION

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The Penman - Monteith (PM) equation is widely accepted as a tool for transpiration estimates using standard meteorological data. The weak point of this approach is estimation of the surface (canopy) resistances (r_c), in PM equation. Empirical equations parameterizing measured canopy resistances are of limited use. Problems with r_c estimation lead to calculation of potential evapotranspiration (E_o) first, then to its reduction to the actual evapotranspiration (E), using relation of E/E_o to the soil water content (SWC) . This contribution presents a method of r_c estimate based on the experimentally verified relations between r_c and SWC.Procedure is as follows: first, using PM equations for potential and actual evapotranspiration, well known relationship between r_c/r_a and relative transpiration E/E_o is used, (r_a - aerodynamic resistance).Two unknowns can be found in this relationship: r_a and E, therefore, aditional equations can be used. Aerodynamic resistance can be estimated independently to calculate E_o. Second, universal relationship $E/E_o = f$ (SWC) is used to eliminate E/E_o in the first equation. This relationship can be expressed by the van Genuchten's type of equation, coefficients of which depend on soil properties. The abovementioned approach enables calculation of r_c using the standard meteorological data and average SWC of soil root layer during the period concerned.

STOMATAL AND SURFACE CONDUCTANCE OF A SPRUCE FOREST: MODEL SIMULATION AND FIELD MEASUREMENTS

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Surface canopy conductances of a spruce forest in the Solling hills (Central Germany) were derived from long-term eddy correlation and gradient measurements of *LE* and *H* fluxes using the rearranged Penman-Monteith equation ("Big-leaf" approximation) during May - September 1996. They were compared with canopy stomatal conductances modelled by an one-dimensional non-steady-state SVAT model (SLODSVAT). It is based on energy and matter budget equations and estimates the canopy stomatal conductance by integrating the response of individual leaves to influencing abiotic and biotic factors ("bottom-up" approach), that provides a dynamical coupling of the stomatal functioning, the transpiration and the CO_2 assimilation of forest canopy with the microclimatic conditions of the atmospheric boundary layer, with the canopy structure and with the canopy and soil hydrology.
The results indicate an insignificant difference between calculated surface and modelled stomatal conductances. Over the measuring period, their ratio ranged between 0.7 and 1.4 depending on weather and soil water conditions. In general, surface conductance estimated by the Penman-Monteith approach was slightly higher than canopy stomatal conductance modelled by the SLODSVAT.

HETEROGENEITY OF LEAF STOMATA CLOSURE AS A PROTECTIVE PLANT REACTION AGAINST DROUGHT

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In pot experiments, the changes in winter wheat and spring barley stomata behaviour under water-temperature stress, simulated at the beginning of reproductive stage of growth have been studied. In this period, compensation of negative stress effect in plants via their growth and developmental processes occurs only in the limited extent. Relative water content (RWC) and diffussion resistance (rs) of stressed leaves have been measured simultaneously. The measurements enabled to detect specific stomata reactions from view point of their heterogenous closure and other adaptive leaf reactions (movement, morpho-physiological changes, etc.), too. The relationship between RWC and rs depended on stress operation rate. During the slow plant dehydration, the course of relationship mentioned was nonlinear, determined by the chemical signal moving from root to shoot. Correlation between RWC and rs of adaxial and abaxial stomata was significantly different and if compared in wheat and barley plants, expressed the modifications in signal perception and distribution in the whole plant structure. During the fast plant dehydration, the course of the relatioship became more linear and overthrew the distinct genotype differencies. The results are dissscussed from view point of their use in the ecophysiological canopy assessment, more precise specification of biological components, implicated in the mathematical models of plant water regime, production process and toleration to drought.

CANOPY RESISTANCE MODELLING FOR CROPS IN CONTRASTING WATER CONDITIONS

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Altought canopy resitance to vapour water transport (r_c) depends on climate and crop water status, standard constant daily values are usually used. So that models using r_c to predict evapotranspiration (ET) fail if crops are under water stress. On the other hand, in scientific literature it is possible to found daily r_c models depending on soil moisture, but, in this case, they need to be calibrated for each crop and site. Here a "climatic resistance" (r^*) is introduced as function of the thermodynamical state of the atmosphere (available energy, vapour pressure deficit and air temperature). Therefore a model of canopy resistance is presented on a hourly and daily time scale, where r_c is expressed as function of r^*, aerodynamic resistance, r_a, and predawn leaf water potential (PLWP). PLWP indicates the crop water status before dawn, when the water status of plants and soil are in equilibrium, so that it is indipendent on the soil type. The model has been tested in outhern Italy on grass (reference crop), sorghum, sunflower and soybean. The odel was validated in France on soybean, without further calibration. The field rops were submitted to several water stress cycles: PLWP ranged between -0.1and 1.2 MPa. The experiments showed that this model works well both in good soil vater conditions and in water constrains. The test of the model, using a data set rom another site, showed that it is indipendent on the site but only on the crop species.

SPECTRAL RATIO AS AN ALTERNATIVE TO LEAF AREA INDEX IN EVAPORATION MODELLING

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Relationships between leaf area index (LAI) and canopy resistance are an integral part of most SVAT schemes. SVAT models therefore need estimates or measurements of LAI to operate. LAI is generally laborious to measure and for forest ecosystems rarely available. The sparseness of LAI data and the known non-uniqueness of the relationship between LAI and canopy resistance are major factors limiting the application of SVAT models.

Measurements of canopy spectral reflectance - especially ratios of measurements in the near-infrared and red spectra (RVI) - have been shown to be well correlated with green LAI and directly with canopy resistance, suggesting the use of RVI as an alternative to LAI in SVAT modelling. Based on frequent measurements of green LAI, RVI, TDR measurements of root zone water content, and a specially developed water balance model, the use of either i) measured green LAI, ii) green LAI calculated from RVI measurements, and iii) RVI directly in water balance calculations has been explored for winter wheat. Based on the comparable results, measurements of RVI for crops and forest stands where LAI measurements were not available were then used to model the water balance of these diverse ecosystems with very encouraging results.

HS7/OA22 Hydrological, oceanic and atmospheric processes governing heat and mass balances at northern latitudes: experiences from NOPEX and BALTEX

Convener: Halldin, S.
Co-Convener: Alestalo, M.

Sponsorship: BAHC, BALTEX, NOPEX

DISTRIBUTION OF SOIL MOISTURE AND GROUNDWATER LEVELS IN THE PATCH AND CATCHMENT SCALES

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The purpose of this study is to investigate the relationship between groundwater levels and soil moisture content in small drainage basins in a landscape dominated by boreal forest and till soils. The data were collected during the Northern Hemisphere Climate Processes Land Surface Experiment (NOPEX). Soil moisture content in the unsaturated zone and depth to the groundwater level show characteristic patterns which are related to the landscape elements (patches) of the drainage basins. Based on a physical description of the soil, distribution functions of soil moisture content conditioned on the depth to the groundwater level have been found, both for the patch scale and the basin scale. These distribution functions is the basis for a procedure for upscaling the patch scale variability of soil moisture to the the basin scale based on soil physcical parameters and depth to the groundwater level. Since the same patterns are observed in different drainage basins, it can be concluded thet the characteristic spatial scale of variations of soil moisture content and depth to the groundwater level within the till soils of the NOPEX-area is given by the size of the investigated drainage basins.

THE RELATIVE IMPORTANCE OF STOMATAL AND BOUNDARY LAYER RESISTANCES IN A COMBINED ENERGY-CO_2 MODEL

A. Verhoef and S.J. Allen (Institute of Hydrology,Wallingford OX10 8BB, UK)

A two-layer SVAT model, describing the fluxes of water vapour and CO_2, has been developed. The model has been tested using micrometeorological measurements over a sparse Sahelian savannah consisting of scattered shrubs with an understorey of grasses, forbs and bare soil. The parameterization of the surface conductance is based on a physiological photosynthesis-conductance model (Jacobs, 1994). The relative importance of the stomatal and the aerodynamic resistances, especially the leaf boundary layer resistances, in obtaining predictions of evaporation and CO_2 fluxes has been investigated. It appeared that under the atmospheric conditions prevailing during the experiment the boundary layer resistances are much larger than the values predicted by the equations usually employed in SVATs.

Jacobs, C.M.J., 1994. Direct impact of atmospheric CO_2 enrichment on regional transpiration. Ph.D. thesis, Agricultural University Wageningen, the Netherlands, 179 pp., ISBN, 90-5485-250-X.

;PACE AND TIME VARIABILITY OF THE SUBCLIMAX COMMUNITIES)F PICEA ABIES WATER REGIME AT THE UPPER FLOW OF)AUGAVA, VOLGA AND DNEPR

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:he sources of three large rivers of Europe - Daugava, Volga and Dnepr are ituated on the plane watershed in the Central part of Russian plain. For this part of he main Caspian-Baltic watershed (56° N, 33° E) it is characteristic: 1) normal ınd superfluous moisturising (precipitation more than evaporation) under the onditions of high level of soil-ground water; 2) weakly dissected relief with hallow beds of small water flows (considerable part of ground drain cannot be aking into account by a standard hydrological method); 3) high degree of ıfforestation under the domination of weakly disturbed subclimax spruce forest of outh taiga types; 4) the lack of nitrogen; 5) weakly expressed trend in century ourse of air temperature and precipitation. Due to climatic and relief :haracteristics on this watershed plain the forest is the main regulator of water ıalance and hydrological regime of small rivers. During the 25-years of complex nvestigations and active field research at 1990-1994 period the data were gathered hat characterise the influence of air temperature, precipitation and VPD on the ·arious parameters of water regime of subclimax spruce forest in the row of ·ligothrophic moisture. The characteristics of water regime are shown for the ·eriodically repeated draughts and for the summer periods with superfluous noisturising. It is also shows that the effects of water deficit can be observed under he considerable store of lightly accessible moisture in soil.

HIGH TEMPORAL AND SPATIAL VARIABILITY OF SURFACE RADIATION BUDGET COMPONENTS

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For May 1993 and June 1993 (BALTEX) radiation budget components at surface were inferred using NOAA-AVHRR and Meteosat data. The target area covers the watershed of the Baltic Sea, approx. an area of 1800 x 3000 km^2. To calculate the radiation budget components at surface from remotely sensed data, a complex analysis scheme could be applied. This scheme contains: a detailled cloud classification to define the microphysical cloud properties, a snow/sunglint threshold technique, a landuse classification for clearsky conditons, a determination of cloud optical properties, and finally the determination of surface radiation budget components. The last two modules are based on an inverse technique, which uses a two-stream approximation for radiative transfer and additional informations from synoptical data. The influence of clouds were investigated either for single-layered and for multi-layered clouds, where significant differences could be found. All these results together give an information about the temporal and spatial variability of cloud cover and radiation budget. A comparison of the inferred results with surface based observations and with model generated radiation budget components will conclude this presentation.

A new land surface treatment for HIRLAM. Comparison with NOPEX data.

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For the limited area weather forecast model HIRLAM has been developed a new land surface treatment based on the "ISBA model" of Meteo-France. For vegetation the ISBA model treats surface resistance and for soil temperature and moisture is used a force-restore model. Five kinds of subgrid surfaces can be used. In each grid square, the surface fluxes are weighted according to the areal fractions of the subgrid surfaces. Physiographical databases are used to assign geographically dominating vegetation and soil type. A HIRLAM forecast with 162 by 142 grid squares of resolution 5.5 km has been made for Southern Scandinavia in the fine weather day of 13 June 1994 with surface fluxes and other variables measured in the NOPEX area. Both model results and measurements at fixed sites and from aircraft, show larger values of Bowen ratio β for forest than for field as expected. The β-values of HIRLAM were somewhat too small, mostly due to somewhat too high settings of initial soil moisture. Further model comparisons will be made for vertical diffusion schemes including a new E-ε scheme. More detailed landuse data for the NOPEX area and effects of initial soil moisture will be tested.

LEAF DISTRIBUTION IN OAK, ASH AND LIME TREES AND THEIR IRRADIATION AS A BACKGROUND FOR SCALING

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Vertical distribution of leaf dry mass (M_d) and area (A_d) of *Quercus, Fraxinus* and *Tilia* species is described in an old growth stand of floodplain forest in southern Moravia as related to different levels of relative irradiation, I_r (I_r above the stand = 1) within a closed canopy. Distribution of actual and effective parameters of foliage was evaluated. The effective parameters, i.e., sunlit or solar equivalent leaf mass (M_s) and area (A_s) were derived when actual ones are weighted with the relative irradiance, I_r at appropriate levels. Stand LAI was 5 (7 when including shrub and herb layer) and sunlit parameters of foliage reached about 1/4 of that amount. Vertical profile of both I_r and leaf dry mass to area ratio (ρ_d)was sigmoidal in all species and both variables were closely linearly related. This feature can be applied as a simple method for estimation the profiles of relative irradiance in field conditions. From an energy standpoint it is clear, that the most important part of tree crowns are their upper layers. So the dominant, upper canopy species had larger proportion of sunlit foliage then suppressed ones in the lower canopy. Similarly in stands the large trees are most important: about 1/3 of the largest trees represents about 2/3 of sunlit leaf area. Since the sunlit leaf area corresponds to transpiration, this biometric parameter is suitable for scaling.

CLIMATE SIMULATIONS WITH THE HIRHAM LIMITED AREA REGIONAL CLIMATE MODEL O VER SCANDINAVIA

Ole B. Christensen and Jens H. Christensen (Danish Meteorological Institute, Lyngbyvej 100, DK-2100 Copenhagen Ø, Denmark)

Regional models are often used as a tool to downscale fields from coarser-resolution GCM simulations. Experience shows that even resolutions down to 50 km do not resolve spatial detail to adequately describe effects of mountains and other geographical features, essential to principal climatological parameters like surface air temperature, precipitation, snow cover, or runoff.

For this reason a very-high resolution regional climate model has been used to investigate the hydrological balance over Scandinavia, a region well described by observations. We present results from simulations with the HIRHAM model, which is based on the HIRLAM weather-forecast model, but with the physical parametrization used in the ECHAM4 global model of the Max-Planck Institute in Hamburg.

Ten years of output from the recent control experiment performed at the Max-Planck Institute with the coupled ECHAM4/OPYC global model in T42 resolution have been used as boundary conditions for HIRHAM in 56 km resolution in a region covering the North Atlantic and Europe. Output from this simulation has been used as boundaries for the present very-high-resolution simulation (19 by 19 km) in an area over Scandinavia and the North Sea.

Results from this control run will be presented, with special emphasis on the hydrological cycle. The results compare favorably with climatological values from the Scandinavian countries.

Evaluation of the threshold methods over a boreal region: a case of study based on radar data.

Crochet. P. (University of Oslo, Department of Geophysics, P.O. Box 1022, Blindern, N-0315 Oslo, Norway).

Since several years, the so-called threshold methods have received much attention for indirect estimation of precipitation based on remote sensing measurement. Most of the studies have been focused on the tropics, mainly because of the recognized importance played by tropical rainfall on the global atmospheric circulation and the Earth's climate. The purpose of this presentation is to evaluate the validity of these methods over a boreal region. The study is based on the radar database developed for the purposes of the NOPEX experiment, during the summer 1995. We will show the importance played by the intermittency phenomenom on the spatial and temporal distribution of rainfall. Two cases of study will be presented: i) the linear relationship between the mean areal rainrate and the Fractional Coverage Area above a given threshold rainrate, ii) the linear relationship between the Fractional Time Raining above a given threshold rainrate and rainfall amounts accumulated throughout periods of time ranging from one day to one month. These results are relevant to the statistical behaviour of the precipitation systems and show the potentiality offered by the threshold methods for remotely-sensed measurement of rainfall over the boreal region.

SOIL MOISTURE RETRIEVAL WITH SSM/I IN THE BALTEX AREA

M. Drusch and C. Simmer (Meteorological Institute, University of Bonn, Germany)

Modeling energy- and watertransports between the earths surface and the atmosphere requires a realistic surface hydrology. Therefore the knowledge about the large scale distribution of hydrological parameters is of high interest. At frequencies exceeding 19 GHz, which are used by current satellites, the measured passive microwave radiances are influenced by soil properties, the vegetation layer and the atmosphere. From precipitation measurements and model calculations from REMO (REgional MOdel) with a horizontal resolution of 18 km we calculate the API (antecedent precipitation index). The API is scaled up to the size of SSM/I 19 GHz pixel (60 km), taking into account the exact location and shape of the elliptical satellite pixel and the antenna pattern for the SSM/I radiometer. Up to four SSM/I overpasses were used to calculate the daily polarization ratio (difference between vertically and horizontally polarized radiances) to minimize atmospheric effects. A comparison between soil moisture measurements at 10 test sites in Germany during May/ June 1993, the API and SSM/I measurements of the polarization ratio show positive correlations. In the second half of this period the vegetation water content increases, so that the polarization ratio decreases and the soil moisture signal is gradually attenuated. In addition there are ambiguities in the timeseries related to the fact, that the coupling of radiation from different surface components, as expressed by the radiative transfer equation, is nonlinear.

A fuzzy disaggregation approach for the estimation of land surface fluxes at the landscape scale

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This paper presents a methodology for the representation of variability in land surface fluxes across a given domain. Remotely sensed thermal data are employed to estimate the variability of the energy partition at a given time, which are then used to map the estimates of the landscape fluxes into the space of modelled functional types of surface response using fuzzy measures. The identified fuzzy weights may then be employed to derive time series of the mean areal latent heat flux and quantiles to represent the range of the flux variability. Large uncertainty must be associated with the derivation of the energy partition but may be explicitly incorporated into the identification of the fuzzy areal weights. This scheme has the advantage that the fuzzy weights may be updated with additional data. The methodology is demonstrated with data from the FIFE domain.

THE BLENDING HEIGHT APPROACH TO ESTIMATE AREA-AVERAGED SURFACE FLUXES FOR THE NOPEX AREA

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Modelling fluxes from heterogeneous land surfaces requires aggregation rules to estimate effective surface fluxes and parameters. The NOPEX area is characterized as a mosaic type landscape by Halldin et al. (1996). We postulate that if the NOPEX area can be classified as a mosaic type landscape, aggregation rules for heat and momentum flux as proposed by Claussen (1991) should apply. In order to check this we use aircraft data from a number of different stability conditions from the NOPEX campaign in 1994 and 1995. We use flux data from 100 m above ground. This flight level is taken as a hypothetical blending height from which the maximum length scale of the land surface is determined. The flux signature of land surface heterogeneity smaller than this maximum scale cannot be identified at this level. We have analysed three days of the campaign in 1994. We find that the blending height concept can be applied to two of the three days. Buoyancy driven turbulence is dominating one case which results into a blending height of about 200 m.

VALIDATION OF NEW SSM/I-CLOUD LIQUID WATER ALGORITHMS OVER THE BALTIC SEA

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The cloud coverage as part of the hydrologic cycle plays a very important role in the global energy balance and additionally it represents a prognostic variable in numerical weather prediction models, like REMO. For the understanding of the cloud induced effects extended measurements by remote sensing are necessary. Methods of deriving the liquid water path by passive microwave remote sensing are not very exact at present, errors of 100 g/m2 are typical values. In the past many efforts have been done to improve existing types of algorithms, but the main disadvantage is the missing true data for the validation of these formulations, apart from some validations in special cases. New types of look up tables have been constructed, using empirical orthogonal functions (EOFs) of the brightness temperatures. These algorithms are trained in a special way having applied a large dataset of radiosonde ascents under the use of the radiative calculation with the IFM derived radiative transfere model "MWMOD". The final formulations are tested with (1) a SSM/I dataset of cloudfree observations and (2) SSM/I brightness temperatures from the PIDCAP phase of the BALTEX project, compared with ship born radiometric observations as a ground truth. It will be shown, that the new EOF-analyzed look up tables give better results with respect to bias and root mean square than the existing algorithms can do.

VALIDATION OF NUMERICAL PRECIPITATION FORECASTS BY IN SITU MEASUREMENTS AT SEA

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Areal coverage of precipitation at the Baltic Sea can be obtained from weather forecast models, seaward looking radars and microwave remote sensing. These methods need ground truth at sea. Therefore, as a contribution to the Baltic Sea Experiment (BALTEX), four ferry ships have been equipped with ship rain gauges that had been developed at the Institut für Meereskunde and a GPS receiver. The ferries shuttle between Lübeck or Travemünde in Germany and Helsinki or Hanko in Finland thus crossing the main body of the Baltic Sea. A fifth gauge is fixed at an offshore mast north of the island Darss. This mast is located close to the ship's track so that a frequent check of the representativity of rainfall measurements at sea is possible. This in situ dataset of precipitation has been used for an intercomparison with numerical precipitation forecasts given from the 'Europamodell' (Deutscher Wetterdienst, DWD) and the 'REMO' (Deutsches Klima-Rechenzentrum, DKRZ). The 'REMO' was operated with two different model physics implemented. Data from the 'REMO' were available for the PIDCAP-period (autumn, 1995) only. The forecasts from the 'Europamodell' (Aug, 1995 to Nov, 1996) generally agreed well with the in situ measurements of the ships.

REGIONAL HEAT FLUX OVER THE NOPEX AREA ESTIMATED FROM THE EVOLUTION OF THE MIXED LAYER

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A method to determine the regional integrated heat flux from measurements of the evolution of the mixed-layer is presented. The necessary input for the method can be deduced from sucessive radiosoundings. The regional heat flux over the NOPEX experimental area was determined for three days of the campaign in 1994 and was found to be almost two times bigger than the measured heat flux over agricultural fields in the area. The NOPEX area is inhomogeneous with patches of forest, agricultural fields and lakes.

FIRST STEPS TOWARDS A FULLY COUPLED BALTIC SEA OCEAN - ATMOSPHERE MODEL

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To explore and quantify the various processes which determine the space and t ime variability of the water and energy cycle of the Baltic Sea and its drainage basin it is necessary to understand the coupled system of ocean and atmosphere. Salt water inf low from the North Sea is one of the important processes which is strongly depe ndend on the atmospheric driving conditions. Sensitivity studies showed that the Kiel Baltic Sea model can only reproduce these features if it is driven with r ealistic atmosp heric forcing. During the PIDCAP period an intensive cyclonic development was ob served which led to an extrem cooling of the oceanic mixed layer. Simulations with REMO show the influence of the SST on to the atmospheric flow field. As a first step towards a fully coupled system of REMO and the Kiel Balti c Sea model some sensitivity studies have been done varying the SST. The results will be shown and if possible validated with observations during the PIDCAP period (Aug.95 to Nov.95).

Relationships between forest characteristics and spectral signatures in high resolution satellite image data

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The scope of this contribution is to examine the information content in multispectral high resolution (visible - mid IR, 0 - 30 meter IFOV) in respect to forest vegetation characteristics such as tree cover density (volume per hectare, basal area and stems per hectare), tree size, age, stand structure and also forest vegetation and soil types. The results are useful for large scale forest inventory and regional estimation of forest biomass and productivity in northern boreal forests. The ground truth data set evaluated consists of objective measurements on more than 1200 objective sample plots with 10-meter radius (Swedish National Forest Inventory design) distributed in two systematic grids designed to represent both the large- and small scale variation within a 100 x 150 km geographic area (NOPEX test site) in central Sweden. The Satellite image data evaluated are 10 SPOT-XS, P and 5 Landsat-TM scenes representing various spatial and spectral resolutions, atmospheric conditions and phenological stages.

WINTEX - Land-surface-atmosphere interaction in a winter-time boreal landscape

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Knowledge of water, energy, and carbon balances during the cold half of the year is also fundamental for climate and weather predictions, for the understanding of water resources and for the global carbon budget. Given the considerable practical and theoretical problems in organising reliable field data collection during extended periods of darkness, subfreezing temperatures and bad weather conditions it is wise to prepare a coming full-scale Concentrated Field Effort (CFE) within the NOPEX framework. It is the objective of WINTEX to provide the best possible planning background for a future CFE through 3 activities: (i) use of meso-scale atmospheric and hydrological models, tested over the NOPEX region with summer-time data and fed with remotely-sensed GIS data, to test special hypotheses and perform sensitivity analyses, (ii) evaluate remote-sensing techniques to test and develop algorithms specific for winter-time conditions, and (iii) perform a limited pilot experiment in March 1997. In connection to WINTEX, a second northern region, around Sodankylä, northern Finland, will be introduced into the NOPEX Continuous Climate Monitoring (CCM) programme. The core of WINTEX is defined by a group of 14 European research groups, funded by the EU Environment and Climate programme. Other groups interested in taking part in the future CFE have already joined WINTEX and this planning project is still open to any interested research group.

SUB-GRIDSCALE PROPERTIES OF ATMOSPHERIC BUDGETS FOR BALTEX

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A goal of BALTEX is to quantify the processes determining the time and space variability of the water and energy cycle. We consider this from two aspects: 1) the integral of a column; and 2) the details of vertical profiles.

1) The integral total column is controlled by the gridscale transports and the molecular transports across the surface. The gridscale parts of the energy and moisture budgets are calculated from the analysed fields of the ECMWF. The time variability of the different energy forms and the transport and storage terms will be presented for the PIDCAP period over the Baltic drainage basin.

2) Resolving the vertical structure of the atmospheric column the sub-gridscale fluxes come into play. The specific profiles describe the mechanism by which the budget is executed in detail. The vertical sub-gridscale fluxes, gained by indirect diagnostic techniques, will be shown and their potential in characterising the meteorological situation will be discussed. For pronounced convective situations the upward convective fluxes are stronger than 300 W/m^2 across the 700 hPa surface.

ENERGY BUDGET OF TWO CONTRASTING LAKES IN NOPEX

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The energy budget of a shallow large lake (Tämnaren, depth 1-2 m, surface area 37 km2) and a sheltered small lake (R=E5ksj=F6, 2-10 m, 1.5 km2) was studied by comparing measurements of the heat energy components with model simulations. One of the models (PROBE) allowed for vertical stratification of lake temperature while the other (Slab-type) assumed well mixed conditions, typical for shallow lakes. The objective was to verify the level of complexity of the thermodynamic scheme needed for the provision of realistic lake surface temperature. Good estimates of lake surface temperature are required e.g. in area-averaged estimates of evaporation. Direct measurement of heat fluxes were obtained with the bulk aerodynamic method using profile data measured at optimal fetch over the lake water. Also the eddy-correlation method was used for verification of the transfer coefficients. Continuous measurements on both lakes included the micrometeorological profiles up to height of 12 m, the radiation components and the lake water temperature profiles. Optical measurements were performed to determine the penetration of solar energy into the water column. Realistic estimates of surface temperature could be produced by both schemes over the summer season using standard meteorological data as input. Sensitivity of the results to the representativity of the input data is discussed.

THE DEPENDENCE OF TURBULENT FLUXES ON SURFACE CHARACTERISTICS OF PLANT CANOPIES

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A realistic representation of the transfer processes at the vegetation-atmosphere interface requires taking into account the surface characteristics of the canopy. With aim to quantify their role in the processes of mass and energy exchange between plant canopies and the surrounding air, the three-layer, one dimensional soil-vegetation-atmosphere transfer model was developed and tested. The verification of the model was carried out through experimental data referring to various field crops. This data was obtained in 1994 at an agricultural site near Lövsta (Sweden) during NOPEX-CFE1. Using this model, the relationships between surface characteristics and fluxes were simulated. An attempt has been made to identify the main factors affecting the surface characteristics of plant canopies for various plant type, soil, and climatic conditions.

Simulation of boreal forest evaporation by a two-layer model

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Partitioning of the total evaporation from a mixed pine and spruce forest in central Sweden was analysed using a modified version of the Shuttleworth-Wallace model. The main modification consisted of a two-layer soil module which enabled soil surface resistance to be calculated as a function of the wetness of the top soil. The model estimates evaporation with respect to interaction between the fluxes from the canopy and the soil surface. The analysis was concentrated to the period 16 May to 31 October 1995 when by using different methods the total evaporation, tree transpiration and forest floor evaporation were measured. A good agreement between the simulated and measured components of evaporation indicates the possibility to use this model as a tool to study the canopy-atmosphere interactions.

A HYDROLOGICAL AND A CLIMATOLOGICAL VIEW OF THE BALTIC WATER BALANCE

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Coorporative climate research within NEWBALTIC (Numerical Studies of the Energy and Water Cycle of the Baltic Region) result in a novel comparison of hydrological and atmospheric climate models.A water balance model of total runoff to the Baltic Basin was developed using the swedish HBV hydrological model representing the daily water balance as closely as possible while keeping the amount of detail to a minimum. A 12-year period of monthly total runoff was evenly divided for use in calibration and verification.Climate model runs representing a 10-year simulation of the current climate were done at MPI using the GCM ECHAM4 model. Temperature and precipitation output from ECHAM4 were used as input to the water balance model over the Baltic Drainage Basin. Large differences in snow water equivalent were observed between the models, which is likely related to the differences in evapotranspiration also observed. The soil moisture routines of the two models showed surprisingly good agreement. Runoff varied significantly. A closer look at the internal processes of both hydrological and climate models is needed.

ARE PERFECT BOUNDARIES REALLY PERFECT?

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Sensitivity studies showed that the moisture budgets are strongly dependent on the chosen analyses fields, in particular analyses derived from DWD and HIRLAM models are used. The understanding of the Baltic energy and water cycle requires detailled knowledge of the physical processes and time scales. Therefore the validation of climate models includes long time series, interannual variability and synoptic and mesoscale weather episodes. The influence of the analyses which are used as lateral boundary conditions to drive the regional climate model REMO will be demonstrated chosing the atmospheric moisture budget as an indicator. Short forecasts (30 h) and 5 days long simul ations with analyses from the German and Danish Weather Services and the ECMWF h ave been carried out using REMO on two different horizontal resolutions and the two available p hysical parameterization packages from DWD and ECHAM4. First results indicate th at the moisture budget calculated by a model-chain with identical physical param eterizations (that means analyses are created by a model using the same or very similar physic s as the driven regional model) differs from the one calculated by a model-chain with different physics. An intercomparison with observations during the PIDCAP period (Aug.95 to Nov. 95) will be shown.

ATMOSPHERIC FIELDS OVER THE BALTIC SEA DERIVED FROM SSM/I OBSERVATIONS

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In order to understand the hydrological cycle — one major objective of BALTEX — results of numerical models, e.g. REMO, have to be used. Before this can be done the results have to be validated. Our effort is to provide validation data, using Special Sensor Microwave/Imager (SSM/I) observations over the Baltic Sea. Two problems appear: (1) development of algorithms, which are capable to estimates atmospheric fields with high accuracy and (2) application of microwave data in small-scale regions such as Baltic Sea, which require the development of techniques to remove land and sea ice influences. It will be shown that algorithms based on neural networks give the highest accuracy and that the new developed technique to remove land and sea ice influences works quite well. The derived fields over the Baltic Sea of cloud liquid water path, total precipitable water and surface speed will be discussed for the PIDCAP period.

DETERMINATION OF ATMOSPHERIC FIELDS OVER THE OCEANS FROM SIMULATED SSM/I DATA USING NEURAL NETWORKS

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Our understanding of the hydrological cycle depends crucial on the availability of observations, e.g. provided by satellites. A large number of algorithms can be found in the literature to determine total precipitable water (TPW), cloud liquid water path (LWP) and surface wind (V) over oceans. Among these algorithms the ones based on neural networks become more and more interesting because they are very effective. Here we show a new method for the training procedure of a neural network which was developed at the University of Kiel. The advantage of this method is its fast convergence so that it needs less computer time than e.g. the backpropagation algorithm. This method is applied to evaluate the Special Sensor Microwave/Imager (SSM/I) data to provide atmospheric fields over the Baltic Sea for the purpose of BALTEX.

SIMPLE HYDROLOGICAL MODEL OF A RAISED BOG

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In applications where the number of parameters for practical reasons has to be kept low, as for Global Circulation Models, there is a pronounced need for simplistic but accurate models describing the hydrological balance for different landscape constituents. As wetlands constitute a great part of the boreal landscape, it is of great importance to understand their role in the hydrological cycle and in the processes of energy and carbon exchange. One of the objectives of NOPEX is to quantify energy, water, and carbon balances over different surfaces within the boreal forest landscape for both daily and annual cycles. Therefore, measurements of groundwater levels, precipitation, unsaturated soil water content and discharge have taken place at a raised peat bog incorporated in the NOPEX programme of continuous climate monitoring (CCM), together with radiation measurements and atmospheric profiles of temperature and water vapour. As the results from the groundwater measurements indicate that the net lateral flow is very small, it could be hypothesised that the hydrological balance in a rain-fed bog can be simulated with a one-dimensional model. Simulations were made with an existing SVAT-model, SOIL. In order to start with a simple approach most of the model parameters were kept constant with the objective to study the model dynamics as a response to the input of the measured data. The preliminary results look promising and further studies will concentrate on the description of the peat as a porous media.

ESTIMATION OF RAINFALL INTERCEPTION OF SPRUCE FOREST STAND BASED ON SPECIFIC LEAF PROPERTIES AND LEAF DISTRIBUTION MODEL.

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Interception of spruce forest canopy was derived on the basis of specific interception of leaf area and known leaf distribution and compared to that measured directly in the field. Norway spruce (Picea abies(L.)Karst.) forest stand in Želivka experimental catchment in Czech-Moravian Heighland, Czech Republic was taken as the model site. Specific amount of intercepted water was estimated in the laboratory as a difference of mass between fresh (but dry surface) and wet branch (rain simulated by spraying of water). Possible impact of wind was assessed when the mass of wet branch was estimated after shaking. The amout of intercepted water was expressed in liters per m^2 of leaf area respectively. Several branches from 3 levels (apex, centre and base of crown) were taken from spruce trees of different age and social position in order to derive the given properties within crowns. Total amount of intercepted rainfall was derived from known leaf distribution within 1 m horizontal layers along crown and known spatial structure of the stand. Good agreement was found between theorcically derived and actual data. The influence of air pollution on rainfall interception due to changed structure of waxes and defoliation was also discussed.

METALS LOADING ON THE GULF OF FINLAND

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Annual and seasonal load of metals on the Russian part of the Gulf of Finland and on their separate basins (Neva Bay, Luga Bay, Koporskaya Bay, Gulf of Vyborg) for the period 1994 - 1995 was evaluated. Helsinki Commission recommendations PLC-3 were accepted as a basis for the research. The calculation was carried out for the following categories of pollution sources:

- riverine inputs in the Gulf;
- treated and untreated municipal, industrial and agricultural water discharges directly in the Gulf (point sources of pollution);
- atmospheric deposition on water surface.

The following conclusion can be drawn:

- Basic source of metals for the Gulf of afinland is riverine inputs (including the outflow from Lake Ladoga).
- Atmospheric deposition is the essential part of metals external load especially for the Gulf of Vyborg , Luga bay and Koporskaya bay.
- Neva Bay is subjected to external load in highest degree. The main sources of metals inputs are Lake Ladoga outflow, waste waters of industrial enterprises and the municipal treatment plants.

ESTIMATION OF ENVELOPING SURFACES OF ROOT SYSTEMS IN LARGE TREES IN FLOODPLAIN FORESTS USING THE IMAGE ANALYSIS SYSTEM.

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Enveloping surfaces of tree root systems, i.e., certain interface between the rooted and non-rooted soil volumes, through which pass water and nutrients were evaluated using the image analysis system DIPS 4.0vsd (Brno, Czech Republic) in order to get an idea of the true conducting area of root systems and of the background for interpretation of data obtained by underground radar technique. Three levels of such surfaces were distinguished on immages of root systems of large trees obtained in the field in a separate study: (1) Level of the entire root systems (as if all roots of a tree occupy a single large „pot"). (2) level of root branches (separate rooted „globules" of soil along main roots) and (3) level of individual roots (geometrical surfaces of roots with diameters >1 cm). The level of root branches seems to be the most realistic when expressing the enveloping surface of root system, because the rooted globules include even fine roots, root hair and mycorrhiza, which are difficult to quantify another way. The immage analysis system was found as suitable recent technique for such kind of studies applicable under field conditions.

Soil Moisture Analysis by Assimilating Atmospheric Observations

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In atmospheric modeling, specification of soil moisture determines to a large extent the relative magnitudes of sensible and latent heat fluxes (Bowen ratio) and therefore the diurnal evolution of the planetary boundary layer. Deep soil moisture content evolves on time scales of several days or weeks, so it can not immediately adapt to atmospheric conditions, and its incorrect specification may downgrade the atmospheric weather forecast over longer times.
Soil moisture is not observed on a routine basis over large scale areas in order to initialize them in numerical weather prediction models.
Using a stand alone soil and atmospheric boundary layer model, the feasibility of off-line variational soil moisture analysis by assimilation of near-surface atmospheric observations is investigated. The experiments are performed using the operational regional forecast model of the German Weather Service.
Assimilation experiments indicate that atmospheric information allows to initialize soil humidity to realistic values even under non-perfect conditions. Minimizing a cost function measuring the misfit between the model's 2m temperatures and humidities, respectively and the corresponding observations, the variationally retrieved soil moisture controls the relative magnitudes of the model's sensible and latent heat fluxes.
It's an encouraging result, that the errors of the operational near-surface temperature and humidity forecasts are reduced significantly by the assimilation of atmospheric observations, as shown for an early spring period in 1994.

COMPARISON OF TWO SIMULATION MODELS OF RAINFALL INTERCEPTION IN A BOREAL FOREST

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In the NOPEX region, Norunda is the local field study site, which represents the relatively extended forests in the region. Rainfall and rain-throughfall were measured during the summers of 1995 and 1996 and the data-set will be used to apply two different approaches of interception simulation. Rainfall interception is often simulated by application of the well-known, Gash-Rutter analytical model. In this study this model will be compared to a model based on an exponentional equation. The concept of the so-called minimum method for derivation of canopy storage capacity (S) and free throughfall coefficient (p) by the Leyton-analysis, is compared to the concept of a maximum S. A maximum storage capacity, which is twice as high as the S found by the minimum method, has already been derived by comparison of flux data during rainfall events.

BALTIC AIR-SEA-ICE STUDY - A field experiment of BALTEX

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The planned Baltic Air-Sea-Ice Study (BASIS) is a sub-project of the Baltic Sea Experiment (BALTEX). BASIS aims at an improved understanding and modelling of the energy and water cycles during winter conditions by conducting a winter field experiment in the ice edge zone of the Baltic Sea in February-March 1998. That will be the first field experiment in the Baltic Sea covering the various branches of physical oceanography, sea ice research, marine meteorology and remote sensing. We will collect data particularly of 1) exchange of heat, moisture and momentum between the air, ice and sea, 2) structure of atmospheric and oceanic boundary layers and their interaction with the exchange processes, 3) ice motion and the atmospheric and oceanic driving forces on it, and 4) the interaction between the thermodynamic and dynamic processes in the air, sea and ice. Analyses of the data sets will result in improved remote sensing algorithms and, in particular, better parameterizations of air-ice-ocean interaction processes for development, validation, and optimization of the coupled atmosphere-ice-ocean models. Financial support has been applied from the EU and this defines the final extent of the project.

ON THE WATER, HEAT AND SALT BALANCE OF THE BALTIC SEA

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Understanding the role of the Baltic Sea in energy and water cycles requires models for the relevant transport processes. Models must be capable of accurately representing the responsde of currents and sea level to direct forcing by the wind, and by wind-induced changes of sea level in the Kattegat leading to exchange flows through the Danish Straits. The models must further describe the response of the circulation to forcing by river runoff, precipitation/evaporation and by melting/freezing, with specific emphasis on freshwater budget and thermohaline circulation. A coupled ice-ocean model is utilized to investigate the water, salt and heat budget of the Baltic Sea for the years 1992/1993. The oceanic component is a three-dimensional baroclinic model of the whole Baltic Sea, with a horizontal resolution of 5 km and 28 vertical levels specified. The ice model is based on the Hamburg Sea Ice Model, with the same horizontal resolution. The coupled system is driven by atmospheric data, mostly provided by the Europa-Model of the German weather service. River runoff is taken from a monthly mean data base. From the two-year model run, the different components of the water, heat and salt budget are identified, and analysed in view of the their contribution to the heat, salt and water cycle.

LONG-TERM VARIABILITY OF ENERGY AND AND MOMENTUM FLUXES FROM FOREST AND FIELD: RESULTS FROM NOPEX CCM-PROGRAMME

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Long-term monitoring of climatic variables and fluxes of sensible and latent heat and momentum are an important part of the NOPEX CCM (Continuous Climate Monitoring) programme. Two sites, one forest and one agricultural, have been selected for these studies which began in June 1994. The sites are adjacent to each other in the Uppsala region in central Sweden. At the foret site fluxes are measured at three heights above the forest by eddy correlation systems built on sonic anemometers and closed path gas analysers. At the agricultural site, with a less extensive measurement programme, only sensible heat and momentum fluxes are measured using a sonic anemometer. The paper present and discuss the seasonal variation of energy partitioning, momentum fluxes etc for the two and a half year record obtained so far. This period include both dry and wet growing seasons as well as warmer and colder than normal winters with and without snow cover.

AN APPLICATION OF A LARGE SCALE DISTRIBUTED HYDROLOGICAL MODEL OVER THE ELBE REGION.

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A first step toward coupling distributed hydrological models with mesoscale atmospheric models is an offline coupling of atmospheric forcing with an hydrological model. The VIC - 2L model (Xu Liang) is a two layer SVAT scheme for general circulations models and numerical weather prediction models. It includes a canopy layer and the effects of spatial subgrid variability of soil moisture. A reasonable hydrologically runoff mechanism will be described, considering the variation of infiltration capacity within a grid box. In the lower layer drainage is represented by the Arno scheme. It has participated in the PILPS experiments. Coupling to the horizontal flux domain, a routing model describes both the concentration time for runoff reaching the outlet of a grid box, as well as the water transport in a river network. These coupled model is set up on a rotated grid of about 1/6 degree of the atmospheric regional scale model (REMO) used in the BALTEXproject. The model has been applied over the main catchments of the German part of the Elbe river (about 40000 km^2), using observed meteorological data on a daily basis. Time series of calculated and measured streamflow for a ten years period have been compared and the results are discussed.

THE PILPS-2C EXPERIMENT, EXPERIENCES AND RESULTS

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The setup, experiences and results of the PILPS-2c workshop will be presented. PILPS, the Project for Intercomparison of Land Surface Parameterisation Schemes, is designed to improve the parametrization of the continental surface, as represented in climate and numerical weather prediction models. In the PILPS-2c experiment 16 current land surface parameterisation (LSP) schemes were forced at time and space scales comparable to their applications in numerical weather prediction and climate models. 10 years of atmospheric data in 61 1° by 1° grid boxes in the Red - Arkansas River basin (USA) are used to force the 16 LSP schemes offline. Model output is compared to measured river streamflow, atmospheric budget analysis from radiosonde data and climatology. The intercomparison shows the differences in the space-time patterns of the energy and water fluxes among the models, indicating further research needed in large scale conceptualisations of current LSP schemes. Although the PILPS-2c basin is not located at nothern latidutes, the experiences from its setup, data requirements, data handling and model intercomparison study should be utilised in further large scale land surface experiments, e.g. as planned within BALTEX.

SNOW COVER SIMULATIONS IN THE BALTEX AREA USING ATMOSPHERIC CLIMATE MODELS

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Snow cover is an important component in the energy and water cycle. In the BALTEX area, a snow coverage influences the interactions between the soil and the atmosphere from late September to early June. Snow melt in spring mainly contributes to the total water inflow into the Baltic sea, which is 483 km^3/ y.

Since the atmospheric processes sensitively react to snow anomalies, a good representation of snow is required in climate models. In comparison to hydrological models both the energetic interactions between snow and atmosphere and the snow properties (mass and area) have to be simulated with a high degree of accuracy.

The results of recent global and regional climate simulations using the MPI model hierachy (ECHAM4/REMO) will be discussed with respect to the snow cover in the BALTEX area. The simulated snow properties as well as the atmospheric parameters which strongly affect the snow cover development will be compared with observations. The climatic relevance of the snow cover will be shown on different time scales.

SINOP - AN INFORMATION SYSTEM FOR DATA RETRIEVABILITY, USABILITY, AND QUERIABILITY

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SINOP (System of Information in NOPEX) contains data from NOPEX concentrated field efforts (CFEs) giving spatial coverage and continuous climate monitoring (CCM) giving temporal coverage. Experiences from SINOP here serve as a basis for a discussion on the rationale for data bases in environmental research. The general objectives of an information system are threefold: to guarantee data *retrievability*, *usability*, and *queriability*, the final goal of the information system being to make it a public information source. If we are promising long-term data-series, as in the NOPEX CCM program, with a life span exceeding both Ph.D. programs and normal research programs we can not rely on the memory or notes of individual researchers for future usefulness of the collected data. The output from the instruments used must be coherent and time stable to guarantee comparability in a set of variables. This can be achieved by inter-comparison and calibration programs. We are currently encouraging the submission of preliminary data, but require a declaration of the quality status. As the use of SINOP increases it will become increasingly interesting to be the originator of data sets with a high quality control status. Rules for submission and retrieval of data must be clearly stated in the data policy of the information system. Data growth is presently in the order of 20 Mb/day. There is thus a need for developing automated algorithms that can perform data quality control and warn if quality is poor.

BIOMETRY OF DAMAGED AND HEALTHY SPRUCE NEEDLES IN MEDIUM POLLUTED AREA OF BESKYDY MOUNTAINS, MORAVIA.

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A set of pairs of spruce trees (*Picea abies(L.)Karst.*) was selected in the medium-polluted area of Beskydy mountains, northern Moravia. Both sample trees of each pair were of the same diameter, but of different age and significantly differed in the extent of crown damage caused by air pollution. Needles were sampled from different heights of the canopy and from branches of different orientation. Significant differences in several biometric parameters of needles (e.g., leaf dry mass to area ratio) along the depth of the canopy were confirmed, reflecting their various energetic load. This pointed out the importance of proper biometric description of needle samples taken e.g. for elemental analysis. It was found, that in heavily damaged spruces with enhanced needle fall, the size of individual needles decreased by 10 to 25 % compared to healthy ones. Furthermore, impaired allometric relations of biometric parameters of damaged needles (even young ones) indicated that the entropy of the system (loss of the internal physiological control) increased by about 20 %, what may have important unfavorable consequences.

Numerical simulations of Land-Surface-Atmosphere Interaction and Boundary Layer Structure in NOPEX region

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In this study, numerical simulation results over NOPEX area are presented in comparison to existing observations for the 13th June 1994. Numerical simulations were performed using the MIUU model which is a 3-D mesoscale model with a higher order turbulence closure scheme. A prognostic equation involving the soil and other fluxes is used for predicting the soil temperature (known as the force-restore method). The model simulation results reveal that the near-surface wind pattern is dominated by northwesterly flow of moderate intensity, without any pronounced geographical or diurnal variation, at least concerning the wind direction. Another interesting feature is the very rapid growth of the convective boundary layer during early morning hours, reaching a final depth of approximately 1600 m AGL at midday. Finally, the comparison of the surface fluxes at three measuring sites (agricultural, forest and lake) shows some distinct differences both in terms of the surface heat flux as well as the momentum flux. These differences are analyzed and discussed.

THE INFLUENCE OF CLOUDS ON TERRESTRIAL LONGWAVE RADIATION

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From April until July 1996, ground based measurements of radiation budget components with an half-hourly resolution at the Anchorstation *Tharandter Wald* (near Dresden) were used to study the effect of clouds on the terrestrial radiation. The main task of this study was the determination of empirical relations between the cloud optical thickness and the change of the terrestrial longwave radiation. Thus, the cloud optical thickness could be calculated through an inverse technique based on a two-stream approximation for radiative transfer. The changes in the terrestrial longwave radiation were carried out by comparing cloudy and cloudfree conditions (reference days).

Three different cloud classes consisting of comparable conditions could be investigated: Cumulus, Stratus, and Altostratus. The statistical approaches showed an average change in terrestrial longwave radiation for Stratus with 59 Wm^{-2}, for Altostratus with 39 Wm^{-2}, and for Cumulus with 22 Wm^{-2}. The maximum influences, which could be observed, were for Stratus 69 Wm^{-2}, for Altostratus 64 Wm^{-2}, and for Cumulus 33 Wm^{-2}. These empirical relations dependent on the cloud optical thickness were applied to Meteosat and NOAA-AVHRR data, where more realistic results could be achieved for cloudy conditions.

QUALITY CONTROL OF RADIATION DATA IN THE NOPEX CCM PROGRAMME

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Radiation measurements are important for applications in environmental research. One of the objectives of NOPEX is to quantify daily and annual cycles of energy, water and carbon balance over different surfaces within the boreal forest biome. It is of high interest to produce long-term measurements of high accuracy, which requires reliable equipment and a system for quality control of data. This is carried out within the Continuous Climate Monitoring (CCM) programme. One of the CCM sites is Marsta Meteorological Observatory (MMO) situated in an agricultural field 6 km north of Uppsala in central Sweden. Continuous data of different radiation components already exist since June 1994 and will continue well after 2000. The measurements at MMO are intended to estimate a radiation budget, allow atmospheric correction of satellite remotely-sensed data, and to maintain *in-situ* calibration of radiometers. The quality control is presently manual but will gradually be automated by using interrelationships between different radiation components, the Ångström turbidity coefficients for various wave-length bands during clear days, and Langley-plots. A system for regular absolute and relative calibration is also elaborated.

SEWAB - A SVAT MODEL WITH VARIABLE INFILTRATION CAPACITY AND EXPLICIT RUNOFF FORMULATION

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A soil-vegetation-atmosphere-transfer scheme solves the coupled system of the Surface Energy and Water Balance equations considering partly vegetated surfaces. The scheme is based on the so-called one-layer-concept for vegetation cover with the evaporation from bare soils and wet leaves and the transpiration from dry vegetation beeing calculated separately. The diffusion equations for soil temperature and soil moisture are solved semiimplicitly at a variable number of soil layers.

Tests of the scheme include the drying process of bare sandy soils with development of an evaporation barrier and the behaviour of surface fluxes and soil moisture after rainfall events over bare and vegetated surfaces. Contrary to a force-restore method for soil moisture this soil model shows the development of an evaporation barrier. The three stages of the drying process of soils are simulated with the duration depending on the formulation of the wetness factor.

The scheme is validated with data from the FIFE experiment and participated in PILPS experiments 2a (Cabauw) and 2c (hydrology) (Project for Intercomparison of Landsurface Parameterization Schemes). Results from these experiments are shown. Inclusion of a variable infiltration capacity and the subsurface runoff formulation after the Arno model conceptualization show significant impact on the runoff production.

FLUX-PROFILE RELATIONSHIPS OVER A BOREAL FOREST

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Measurements have been carried out at the NOPEX Central Tower Site ca. 30 km N of Uppsala in Sweden. This site represents a mixed pine-spruce forest of the height of about 25 m. Profiles of wind speed, air temperature and humidity were measured with Solent basic anemometers, thermocouples and a Li-Cor gas analyzer, respectively. 8 levels, from the tree tops up to the height of 87.5 m, were used in the analysis. Two eddy correlation systems (at 35 and 70 m) consisting of Solent enhanced anemometers, platinum temperature sensors and Li-Cor gas analyzers provided directly measured turbulent fluxes. The displacement height was found to be 21.1 m. A roughness sublayer with enhanced eddy diffusivities and decreased gradients could be detected over the forest. This was accounted for by multiplying the traditional non-dimensional gradients with the correction function $\phi=((z-d)/(z_*-d))^n$. It was a linear function of height (n=1) for temperature and humidity with their roughness sublayer height z_*=57 m. Enhancement of momentum exchange and it's extension were lower (n=0.6, z_*=45 m).

SCALING BRANCH CHAMBER TRANSPIRATION MEASUREMENTS ON SCOTS PINE AND NORWAY SPRUCE TO STAND LEVEL

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To improve our understanding of cycling of water and CO2 in relation to environmental factors in the boreal forest ecosystem a chamber system has been developed. This system was used during the summers of 1995 and 1996 to measure transpiration on branches at different heights in a 50 year old mixed pine and spruce stand at the NOPEX site in Norunda, Central Sweden. Functions describing the relation between branch conductances and measured climatic variables has been determined. These conductances will be scaled to stand conductances using stand needle distributions from the winter 1995/96 and the results will be compared to stand conductances derived from sap flow measurements in the same stand and during the same time period as well as eddy covariance meaurements above the stand.

VALIDATION OF DISTRIBUTED HYDROLOGICAL MODEL AGAINST SPATIAL OBSERVED DATA

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The experience of application of a physically-based space-distributed hydrological model, ECOMAG, in a river basin Fyrisan in the NOPEX area is presented. The model considers the main processes of the land surface hydrological cycle: infiltration, evapotranspiration, thermal and moisture regime of soil, snow melt, formation of river runoff , surface and subsurface runoff and groundwater. The spatial integration of small and meso scale non-homogeneity of the land surface is central for the model. ECOMAG is based on uniform hydrological (or landscape) unit representation of the river basin. The river net structure and location of different units reflect the spatial variation of topography, soil, vegetation and land-use types, as well as meteorological conditions in the basin. The disaggregation of the river basin is executed on the basis of regional thematical maps using GIS techniques. As a first step the model was tuned using standard meteorological and hydrological data from the Swedish Meteorological and Hydrological Institute for the period 1981-1995. This step has been followed by the validation of the model against measurements in time and space performed during two CFEs of the NOPEX project in 1994-1995.

RAIN DETECTION WITH THE SSM/I IN THE BALTEX AREA

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Within BALTEX soil moisture and rainfall over land are investigated by SSM/I radiometer on the DMSP satellites. The 85 GHz ($\lambda = 3.5mm$) radiances are slightly reduced by scattering at raindrops while the lower frequencies remain mostly uneffected. This is the basis of rain retrieval according to Grody. The coefficients for this algorithm must be recalculated for the BALTEX area since they depend on the underlying surface parameters. The recalculations were done by linear regression and by neural networks. For validation we use in-situ rain measurements with a temporal resolution of 1 min to ensure simultaneous measurements. These data are available from more than 100 stations in Germany. In our results 189 out of 240 rain events and 477 out of 508 no rain cases were correctly identified by SSM/I for an optimized threshold of the Grody algorithm. Application of neural networks within the Grody formalism gives no improvement. We then trained the neural network directly in order to predict 'rain' or 'no rain' which reduced the error rate for both rain and no rain events by a factor of 2. Apparently neural networks make a better use of the information available. In a third approach we try to predict instantaneous rain rates by using the neural network. Surface qualifier, like vegetation indices will be applied as additional input for the neural network.

A COMPARISON OF CLOUD PARAMETERS FROM THE ISCCP-DX DATA SET WITH RESULTS OF THE REGIONAL MODEL REMO OVER THE BALTEX AREA

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For numerical model calculations of water and energy balances to be reliable, ideally the model should be validated over the whole computational domain with high spatiotemporal resolution. Satellite data are particularly well suited for this purpose. Results from consecutive short time forecasts of the regional atmospheric model REMO (horizontal resolution $\approx$ 18 km) over the BALTEX area are compared with satellite measurements of cloud parameters. The DX data set of the ISCCP (International Satellite Cloud Climatology Project) has a horizontal and time resolution of 30 km and 3 hours, respectively.
The following variables of the ISCCP-DX data set are analysed and compared with model output: cloud cover, liquid and ice water path, cloud top height, and cloud top temperature. There is no unique correspondance between these variables and the prognostic and diagnostic variables of the model. Cloud cover is a continuous variable in each layer of the model whereas the ISCCP-DX data contain a 0/1 cloud flag. Cloud liquid water is a prognostic variable in the model whereas in the satellite data the optical depth is the measured parameter. Attempts to overcome these difficulties are presented. Furthermore, the satellite measurements help to examine if the treatment of cloud ice as additional prognostic variable in REMO improves model performance.

ATMOSPHERE-ICE-OCEAN COUPLING IN THE BALTEX RE-ANALYSIS PERIOD 1986/87

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The atmosphere, the ice and the ocean constitute a physical system with strong coupling. In shallow semi-enclosed seas, as the Baltic Sea, the changes of properties in the upper layers of the sea and in the sea ice are also often rapid. This is due to large variability in the meteorological forcing, large river inflows and the presence of coast lines and islands, which causes divergences in the upper layers of the sea. The development of high resolution weather forecasting models make it now possible to resolve many of the specific features of the Baltic Sea geometry as sub-basins and straits. This together with advanced ice-ocean models give us good possibilities to develop coupled models for the Baltic Sea. A coupled model system using the HIRLAM atmosphere and the BOBA ice-ocean model is now in operational use at SMHI and has also been applied in a BALTEX re-analysis study. The results are most promising but it is necessary to apply manual corrections or data assimilation for the sea surface temperature to avoid drift of the coupled model. The model system as well as results will be presented during the seminar. The development of coupled atmosphere-ice-ocean models within the BALTEX program will also be outlined.

DISTRIBUTION OF LEAF AREA AND CROWN PATTERN OF RHODODENDRON UNDERSTORY IN THE PINE FOREST

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Crown biomass and structure of *Rhododendron ponticum L.* understory which invaded sparse *Pinus sylvestris* forests was studied in two stands, situated in Brasschaat (Belgium). Leaf, shoot and flower bud dry mass, leaf area, shrub height, length and diameter of branches were measured at the shrub level by the "cloud technique" based on destructive sampling. For this typical very dense shrub without the main stem and of complicated branching structure, a two step scaling to stand area unit was applied: (1) Approximation the biomass of shrubs per unit of stand area completely and more or less homogeneously occupied by branches (according to their height instead of diameter). (2) Assessment of gaps and stand coverage by shrubs of different height. All shrubs were analyzed in details in two small homogenous plots with plants of diffemt heights. Height of shrubs was linearly related to branch ground diameter ($R^2 = 0.9$) similarly as dry mass of leaves, shoots, buds and leaf area index (R^2 = 0.86, 0.7, 0.67 and 0.86 respectively). Three-dimensional distribution of leaf area and canopy depth for both plots is presented. It was found that the directly measured LAI within a homogenous shrub (2.36) was very closed to LAI, measured by the LAI-meter LI-2000. Considering the entire stands, mean LAI of shrub understory was 1.8±0.2 representing 121±15 % of LAI of the overstory trees. This shows the importance of leaf area of Rhododendron for the mass exchange of the entire pine forest.

MATHEMATICAL MODELLING OF THE INFILTRATION INTO SOIL WITH CRACKS

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Results of mathematical modelling of the infiltration of water into soil with cracks are presented. Mathematical submodel CRACK is a part of the SVAT model GLOBAL, but it can be used separetely to model infiltration events. Before ponding, rainfall infiltration is simulated by the classical Richards equation as infiltration into homogeneous (non- cracked)soil.When ponding starts, soil cracks begin to fill with water.Lateral infiltration from the water filled part of cracks into soil matrix follows. Green -Ampt approach is used to calculate lateral infiltration.It was shown by the modelling, that soil cracks during a relatively dry, spring - summer periods can absorb and re-ifiltrate to the soil matrix much higher quantities of water then it can be infiltrated through soil surface. For the conditions of NOPEX area (Sweden, near Uppsala) ,volume of soil cracks was able to absorb up to 36 mm layer of water. At the same time (agricultural site Lovsta, May 30, 1994, rye canopy), the infiltration surface of cracks walls was higher up to 5.9 times in comparison to the soil surface. Of course, cracks parameters depends on soil water content distribution at given time. Soil cracks are contributing to "self preservation" of canopies growing under unfavourable soil conditions.

MICROWAVE REMOTE SENSING INVESTIGATIONS FOR MONITORING HYDROLOGICAL PARAMETERS

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Remote sensing techniques are a useful method for monitoring hydrological parameters in large watersheds at a relatively low cost. However, the operational capability of remote sensing is not yet fully exploited and much research is in progress especially on the use of new sensors and on the algorithms for the extraction of geophysical parameters. A significant phase of this study consists of investigating the sensitivity of microwaves to some important parameters (soil moisture, surface roughness, vegetation cover and biomass) which are of primary importance in modelling the geophysical processes of the hydrological cycle. Although the detection of these parameters has been the subject of many investigations, carried out in past years with ground based and airborne sensors, only a very few preliminary investigations have been carried out using data collected with spaceborne sensors. A major problem in retrieving the hydrological parameters is that each of them affects in a different way the microwave signal and separating the effects requires the use of appropriate multi-frequency algorithms. This paper presents an analysis of the achieved results on Sweden (Nopex) and Italian (Montespertoli) test areas aiming at evaluating the contribution of microwave data for estimating some geophysical parameters which play a significant role in hydrological processes.

RELATIONSHIP BETWEEN CLIMATIC VARIABLES AND THE EUROPEAN CIRCULATION PATTERNS: THE BALTIC REGION

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Atmospheric circulation changes are often supposed to be responsible for climate fluctuations. It is obvious that there is a close relationship between circulation patterns and climatic variables. The purpose of this paper is to analyze the relationship between distributions of daily air temperature, precipitation rate and relative humidity and the European circulation patterns. The climatic variables are collected in Estonian, Latvian and Lithuanian meteorological stations during the time period 1977 to 1993. Investigation is carried out for different seasons. There are no large differences between the outcome from different stations. Certain circulation patterns bring about decrese or increse of temperature over the whole Baltic region. Even the highly varying precipitation is strongly linked to the atmospheric circulation. The results could be valuable to work out a method of modeling precipitation as a function of circulation pattern.

DYNAMICS OF SHALLOW GROUNDWATER IN FORESTED TILL SOIL

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Temporal and spatial variations of shallow groundwater levels were investigated in three small till catchments in the NOPEX-area in southern Sweden. The catchments are forested and of low relief. The aim of the study was to develop methods for using landscape information in regional hydrological modelling. Characteristic differences in the temporal variability of the groundwater levels and in their response to rainfall were observed. These differences could to some degree be related to the topography, but moderate variations in the geological conditions were also important. The direction of the groundwater flow in an intensively monitored hillslope, as determined from the gradient of the groundwater table, showed large temporal variations (up to 42 degrees). During periods with low groundwater levels and little streamflow, the flow in the lower part of the hillslope was almost parallel with that of the stream. As the groundwater levels rose, the flow direction became more and more directed towards the stream.

SOLAR RADIATION FLUXES AT THE BALTIC SEA SURFACE

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The implementation of BALTEX foresees the analysis of historical data sets in order to e.g. establish climatological statistics as background information for studies of actual events. An important source for climatological information from the open Baltic Sea, covering time periods on time scales of years to decades, are the meteorological reports made onboard of Voluntary Observing Ships. In this study monthly and annual estimates of incident solar radiation fluxes at the surface of the Baltic Proper are presented and discussed. Solar fluxes are computed using a semi-empirical model applied to ship meteorological observations of the COADS (Comprehensive Ocean-Atmosphere Data Set) from the period 1980 to 1993. Spatial distribution of the fluxes as well as their seasonal and interannual variability are presented. The impact of both meteorological and astronomical factors is analysed. Comparison of these results to estimates based on other bulk parameterisation is included.

CAN SIMILARITY THEORY BE APPLIED IN THE ATMOSPHERIC MARINE BOUNDARY LAYER OVER THE BALTIC SEA

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The objectives of BALTEX include the improvement of parametrization processes in meso- and regional-scale climate and weather forecast models. One important part to improve parametrization schemes is a better understanding of the turbulent exchange of heat, water vapour and momentum between the sea surface and the atmosphere. In this investigation we will focus on the turbulence structure in the unstable and near neutral marine atmospheric boundary layer over the Baltic Sea, in order to examine the limits for Monin-Obukov similarity theory. It is found that the state of the sea will affect the vertical exchange of energy and momentum in For example the non-dimentionized wind gradient is found to be a function of wave age. Two distinct main flow regimes have been identified: (i) a 'regular' type of unstable flow with young waves for which similarity theory applies and (II) an unstable or near neutral boundary layer with older waves or dead sea with very low exchange of momentum between the air and the sea.

The study is based on measurements taken at a very low and flat island (Östergarnsholm) east of Gotland, which includes profile and turbulence measurements, together with recordings from a 3-D wave rider buoy. Simulations with the HIRLAM model have also been performed.

ENERGY AND SCALE OF COHERENT STRUCTURES IN THE ATMOSPHERIC BOUNDARY LAYER

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Which are the dominating scales for the turbulence responsible for the vertical transfer of energy in the atmospheric boundary layer (ABL)? Many studies have shown that the turbulence in the ABL forms in coherent structures, more or less organized structures of transporting eddies. How do these structures depend on stability and height in the ABL and on the surface conditions, and how can they be detected?

In this study, aircraft data from the NOPEX experiment have been used in the analysis of turbulent structures. The aircraft measurements were performed during the two Concentrated Filed Efforts in summer 1994 and spring-summer 1995. Measurements were made in different patterns over the area and for heights from 100 m and up to 0.6-0.8 times the boundary layer height.

One method, which has been shown to be a good instrument for detection of organized structures in the surface layer, is the "modified u-level method" by Tiederman. This method gives the possibility to distinguish between smaller scaled events, ejections, and larger scaled events, bursts and sweeps. This method has here been applied to the aircraft data with good results.

The knowledge of portioning of energy between different scales and how these scales depend on height and atmospheric conditions is important when it comes to parameterization of models. It shows which processes that are important to include and which information is needed for surface characteristics.

A COMPARISON BETWEEN DIFFERENT FORMULATIONS FOR THE SEA SURFACE ROUGHNESS IN A MESO-SCALE NUMERICAL MODEL

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The effect of different sea surface roughness formulations on the wind field in a meso-scale higher order numerical model has been investigated. The relations for the sea surface roughness that has been compared are:

1. a constant value of 0.00025 m
2. Charnock relation which relates the sea surface stress to the friction velocity
3. drag formulations which relates the sea surface stress to the wind speed
4. a new fetch and wind speed dependent relation based on results from measurements.

These relations give a large difference in the sea surface roughness, but the wind field is not affected that much. The differences in the simulated wind fields between the above relations are between 0 - 12 %, depending on wind speed and fetch. The sea surface roughness for different fetches and wind speeds has been calculated using measurements from a tower and wave buoy located at Ostergarnsholm at the east coast of the island Gotland in the Baltic Sea. The different relations for the sea surface roughness have been compared with these measurements.

ATMOSPHERIC ENERGY AND HUMIDITY BUDGETS IN THE BALTIC CATCHMENT AREA DURING THE PIDCAP PERIOD

Bent Hansen Sass and **Xiaohua Yang** (Danish Meteorological Institute, Denmark)

Data-assimilations have been made with the HIRLAM forecasting system in the NEWBALTIC project within the framework of BALTEX. The model setup used for data-assimilations during the period from August 1995 - October 1995 is briefly described. The forecasting system includes cloud water as a prognostic variable. Problems associated with the accurate determination of atmospheric energy and moisture budgets are described. The temporal variation of the individual components of the atmospheric energy and moisture budgets of the Baltic catchment area is presented. This involves a distinction between the effect of dynamical processes and other processes such as radiation, condensation and turbulence. A preliminary comparison on a monthly basis gives good agreement between model estimated precipitation and corresponding measured and analysed precipitation data.

Application of the HBV model to the NOPEX area - regionalization of uncertain model parameters

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The HBV model, a conceptual rainfall-runoff model, was applied to 11 catchments within the NOPEX research area. The catchment areas ranged from 7 to 950 km^2 with between 41 and 87 percent covered by forest. The aim was to find relationships between the different model parameters and physical catchment characteristics. The existence of such relations would allow expansion of the model application to ungauged catchments. Using a 10-year-calibration period the 'best' parameter set for each catchment was determined. Earlier studies, however, demonstrated that there may be many different parameter sets which give similar good results during a calibration period. Therefore, using a Monte Carlo procedure, the uncertainty of the parameter estimation was included into the analysis. The question was not only whether model parameters can be related to catchment characteristics, but also how sure one can be about these relationships.

WATER EXCHANGE RATE IN SATURATED ZONE OF SOME BOREAL PEATLANDS: POTENTIAL IMPLICATIONS FOR HYDROLOGY AND GREENHOUSE GASES

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In boreal zone, peatlands occupy much of the landscape, and have a large influence on water and carbon cycle. The study was initiated by investigations carried out at the West-Dvina Research Station, Russ. Acad. Sci. (56 N, 32 E, Daugava headwaters - Baltic Sea Basin). Water residence time in peatlands of different hydrological types were examined in 1990-1991 based on environmental tritium testing (Sirin et al. 1994). Slow convection up to 2 m depth in the saturated zone on raised bogs and soligenous mires were shown. Deeper waters were dated by 100-150 yrs. Topogenous mire has detectable water exchange (residence time less then 20 yrs) in the whole peat layer. Later on this stratigraphy was indicated by O18 monitoring and was embodied in dissolved gases distribution in peatland waters. The idea of hydrological mechanism of trace gases delivering from deep stratum received further support, and the necessity of water movement studies in "catotelm" was shown. From late 1995 new study sites in Central and North Sweden, representing raised bog and highly productive topogenous mire (both inside NOPEX project area), aapa and slope fens, were involved in research.

Atmospheric fluxes of heat, water vapour and carbon dioxide for an agricultural area within the boreal zone of Sweden.

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Within the framework of NOPEX two intensive field campaigns were conducted at Tisby, 45 km SW of Uppsala. Flux measurements were conducted above typical land-use types including wheat, barley and fallow. Data comparability were obtained by circulating an eddy correlation system between the sites. The atmospheric flux data were supplemented by radiation measurements. The fluxes from the different land-use types were compared, and large differences between sites were revealed, daytime Bowen ratio values were thus ranging between 0.4 and 6. Based on the results models for the canopy flux of carbon dioxed, heat and water vapour were elaborated. For the carbon dioxide the model is based on scaling leaf level fluxes applying the canopy use parameter-approach, while the model for evapotranspiration and heat flux are based on gradients of temperature and humidity between surface and a reference level. Finally remote sensing technique was incorporated. for integrating the result from the separate fields to fluxes representative for the agricultural landscape.

ESTIMATION OF AREAL SOIL MOISTURE USING TERRAIN CLASSIFICATION

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Soil moisture naturally exhibit a high local and regional variation, and any data collection scheme is restricted with respect to the number of point values to be measured. In spite of recent developments in remote sensing for estimating area soil moisture, its applicability remains to be validated for forested areas, and it is still necessary to rely on point measurements. Based on relationships between soil moisture and topographic parameters this study investigates the possibilities to extrapolate from point to area values of soil moisture. A high resolution (5 meters) digital elevation model has been created for the study area. The use of different measures parameterizing the topography (e.g. slope, curvature, wetness index) will be evaluated. The landscape are classified into different patches with similar internal heterogenity in soil moisture. Soil moisture measurements are taken at various scales, including plots of 10x10 meters, transects 100 meters long, and campaign measurements covering the whole catchment. The study takes place within the Buddby experimental catchment (0.5 km^2), which is characterized by its gently slopes, bogs, conifer forests and clear cut areas. Measurements are taken in the top 15 cm of the soil using the TDR method, and the data cover a wide range in moisture conditions.

RADAR PROFILING ABOVE A FOREST CANOPY

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The output signal from a radar altimeter/profiler is related to range and radar cross-section of the sub-reflectors within the antenna beam. By high-resolution range processing, the backscattering from the tree top and the ground surface can be separated and the tree height measured. A simplified model of the radar profiling response from a forest canopy and single trees is described and experimental results from helicopterborne measurements in the NOPEX project using a multi-band frequency-modulated radar are presented and discussed

CROWN ARCHITECTURE AND LAI OF UNDERSTORY PRUNUS SEROTINA IN A SCOTS PINE FOREST: A SCALING-UP EXERCISE

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One of the main understory species, American cherry *Prunus serotina (Ehrh.)*, was measured in planted Scots pine forest in Brasschaat (51° 18' N and 4° 31' E), 12 km northeast Antwerp. Leaf dry mass and area distribution was estimated by the "cloud" technique based on destructive sampling of five model trees of different diameters at breast height (DBH). (1) First, leaf, branch, stem and flower bud dry mass, leaf area, height (length) and diameter of stems and branches were measured at the tree level. Allometric relations were estimated and tree parameters were generalized for the mean trees of different diameter classes. (2) Up-scaling from trees to the stand level, with this understory of rather homogenous structure was based on diameter distribution. (1) It was found that all allometric parameters were closely related to stem DBH (R^2 above 90%). The two-dimensional distribution (by height and radius) of leaf area and dry mass/area ratio in individual trees are presented. (2) At the stand level it was found that the directly measured LAI (4.1) was significantly higher compared with LAI, measured by LAI-meter LI-2000 (2.6). This was contrasting to the results, found in another study with Rhododendron understory in the similar pine stands on the same site, where it was vice versa. LAI of understory were much higher then LAI of overstory pine (1.5). The results represent a background for estimation the role of the understory species in the mass exchange of the entire stand.

SIMULATIONS OVER THE HAPEX-MOBILHY STUDY AREA USING "CLASS" AND THE CANADIAN REGIONAL CLIMATE MODEL

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A growing number of comprehensive, high-quality regional datasets are becoming available from GEWEX and ISLSCP field experiments for the testing of limited-area models and model parametrizations. Yet it is worthwhile to revisit earlier datasets from time to time to enable the testing of models and parametrizations that have been developed since they were collected. This paper describes a series of tests using the HAPEX- Mobilhy database that have been carried out with the Canadian Regional Climate Model (RCM) and CLASS, the Canadian Land Surface Scheme developed for the CCC GCM. Interesting parallels and contrasts are found with the results published by French investigators using the Peridot model and ISBA. The performance of CLASS in single-column mode at the SAMER sites and in the Les Landes forest is reviewed, and compared with its performance over other similar ecosystems using field data. Problems in specifying the initial and boundary conditions for the RCM are described, and the results of sensitivity tests are summarized. The results of runs for the Special Observing Period are presented, and compared with the Peridot model runs and with satellite data.

HYDROLOGICAL AND ENERGETIC CYCLE FOR THE BALTIC CATCHMENT SIMULATED WITH REGIONAL AND GLOBAL MODELS

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Within the BALTEX (BALTic sea EXperiment) project the water and energy fluxes of the Baltic Sea and its drainage basin will be investigated in order to get a better understanding of both hydrological and energetic processes, which is an important aspect to improve the physical parameterization schemes of atmospheric models. The budgets for the Baltic catchment area of multi-year integrations with two global and two regional models will be determined. In particular this are a 10 year T106 ECHAM4 run with AMIP SST's and a 10 year T106 ECHAM4 simulation with climatological SST's, as well as a 10 year HIRHAM integration driven with boundaries of a global coupled run and a 10 year REMO experiment driven with boundaries of the above mentioned T106 run with AMIP SST's. The corresponding fluxes will be discussed in more detail and as far as available also compared with observations.

LATENT HEAT FLUX FROM SMALL SHELTERED LAKES

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In the boreal zone, where lakes are abundant and of relatively small size, their influence on local weather and water balance can be significant. Lakes contribute to the regional energy balance due to their aerodynamically smooth surface, large heat capacity and optical properties that contrast with the properties of surrounding forest dominated land. The development of the internal boundary layer over the lake was measured in the context of NOPEX CFEs with a floating meteorological mast, drawn wind-wise across a small sheltered lake. Long term data was collected with fixed platforms placed at different fetch positions on two lakes of contrasting size. Results indicate that the area averaged latent heat fluxes from forest sheltered lakes can differ significantly from the corresponding point estimates made down-wind over the lake surface. A non-linear effect of lake size on the regionally averaged heat flux should be applied in the case sc. B-type (small patch) landscape heterogeneity.

MODELING OF SURFACE FLUXES ABOVE FOREST CLEARING IN THE NOPEX CFE-2 MEASUREMENT PROGRAMME

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A prognostic surface flux model (acronym PROGSURF), developed jointly at the Universities of Budapest and Vienna, is used for large-scale and mesoscale atmospheric models. A force-restore type soil surface temperature prediction is applied. The soil moisture prediction is made by a 3-layer diffusion method approach. Above land the latent and sensible heat fluxes (LE and H) are determined using Penman-Monteith and energy balance equations. The surface resistances are modeled by empirical formulae. The aerodynamic resistance is calculated using Monin-Obukhov similarity theory taking into account the atmospheric stability. PROGSURF is tested in NOPEX CFE2 measurement programme above forest clearing in a two-week period during June and July 1995. The measured energy budget components are corrected in order to close the daily energy balance. The daily courses of modeled and measured turbulent fluxes are similar but their Bowen-ratios can often differ considerably.

Parsimonious runoff models for seasonally snow covered catchments in Sweden

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The necessary compromise between the desires for both accuracy and simplicity in the past has determined the direction of development of runoff models. Hydrological models that simulate hydrographs of river flow on the basis of available meteorological data would be a valuable tool in the hands of the planners and designers of water resources systems. To enable the applicability to ungauged catchments, the models have to be parsimonious as regards to the number of parameters (unknown constants to be estimated, which are characteristics of the basin). In this study, two models were developed and tested using hydrological data from NOPEX catchments, 4 parameters were found sufficient for the desired purpose and these parameters were characterized. Tentative extension to ungauged catchments was examined.

Optimization and residual analysis of runoff models

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Typically, some of the parameters of conceptual hydrologic models are calibrated using limited hydrologic infomation, namely, input-output time series data such as precipitation and streamflow. In recent years the automatic estimation approach has become the more commonly practiced methods. In this paper, an effective and easily applicable procedure is presented through which two basic issues of model evaluation are accounted for. First, different techniques used for parameter analysis is discussed. Second, methodology of residual analysis is discussed and general behaviours of residuals are demonstrated in a number of graphs. To illustrate the procedure, a simple water balance model was applied to the catchments located in the NOPEX area. The results show that the use of power transformation to stabilize error variance and ARMA(1,0) model to remove autocorrelation appears sufficient for stochastic errors typified by humid hydrology.

HS8.1 Land use change and climate feedback with particular reference to the water balance of semi-arid regions

Convener: Savenije, H.H.
Co-Conveners: Bronstert, A.; Ulbrich, U.

SURFACE WATER BALANCE ESTIMATION FOR A SEMI-ARID REGION USING A REGIONAL CLIMATE MODEL AND COMPARISON WITH ANALYSIS DATA

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Ralf Podzun (Deutsches Klimarechenzentrum, Bundesstraße 55, D-20146 Hamburg, Germany)

We have applied the regional climate model REMO to the Tropics. REMO is based on the Europa Model (EM) of the Deutscher Wetterdienst (DWD) and was adapted to be used in climate research at the Max-Planck-Institut für Meteorologie (MPIfM) and the Deutsches Klimarechenzentrum (DKRZ). We have applied the so-called „nesting-technique" using observed Sea Surface Temperatures (SST's) for the period December 1982 to December 1983. Different runs were performed using modified initialization approaches for the regional model. Before using the model results as driving forces for impact models, the model results have to be carefully validated in several steps. Here, we focus on the model skill in reproducing the surface water balance within the land-covered part of the integration area as well as within a diagnosis area in NEB. We compare the model-simulated components which contribute to this balance with analysis data and available observations. From the validation results we conclude statements on the applicability of the model output for climate impact research and on requirements for improved driving forces and physical parametrizations. In future investigations, it is intended to use modified initial and boundary conditions as well as other physical parametrization approaches.

A LOOK AT THE HIERARCHY OF NON-LOCAL TURBULENCE CLOSURES FOR CONVECTIVE BOUNDARY LAYERS

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The turbulence closure for convective boundary layers (CBLs) is considered. An overview is given of various schemes ranging from simple counter-gradient correction approach to sophisticated closures based on the budget equations for the turbulence moments. The role of the third moments and the transport asymmetry of convective turbulence is emphasised. Appropriate parameterization of the fluxes of fluxes is discussed in the light of the evidence from large-eddy simulations. As an alternative to the conventional line employing more and more sophisticated "turbulent diffusion parameterizations", we propose a "turbulent advection parameterization" for the flux of flux of potential temperature derived from a "minimum-complexity skewed-turbulence model". It meets the requirement of dimension, tensor invariance, symmetry and realisability, and agrees with LES data in the CBL interior. To embrace the entire CBL, an interpolation "diffusion+advection parameterization" is proposed based on the new turbulent advection formulation and the most simple down-gradient diffusion formulation. Then the solution to the potential-temperature-flux budget equation provides a closure for the flux in question. In particular cases it reduces to a number of more specific closures proposed earlier.

HUNGARY: LAND-USE AND CLIMATE INTERACTION

L. Bodri (Geophysics Department, Eötvös University, Budapest, Ludovika 2., Hungary 1083)

Activities like extensive, large-scale river regulation works carried out from the second half of the 19th century, replacing of vast waterlogged areas by cultivated lands and simultaneous deforestation have fundamentally changed hydrological settings in Hungary, giving rise to establishment of prolonged drought situation. Under Hungarian environmental conditions and due to economic mismanagement drought appears as accelerator and intensifier of land degradation and desertification. Increasing of the areas with weakened vegetation cover and barren lands affected both the ratio between runoff and infiltration in favour of the former, and evaporation. At the Hungarian Great Plain the annual potential evaporation of 650-700 mm exceeds the annual precipitation which varies between 500 and 550 mm. At present a decreasing trend in precipitation is characteristic of almost the whole territory of the country compared with only its central regions at the beginning of this century, and its velocity has increased then (up to 2-2.5 mm/yr).

The paper assesses potential land surface feedbacks on the observed rainfall pattern and presents examples of the surface energy balance of rainfed and irrigated agricultural systems.

PREDICTION OF THE EFFECTS OF CLIMATIC CHANGES AND LAND USE MANAGEMENT ON WATER RESOURCES BY COUPLING OF AN HYDROLOGICAL MODEL WITH A GIS

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A methodological framework based on the concepts of ANSWERS (Areal Non point Source Watershed Environment Response Simulation), a continuous, distributed parameters surface model for simulating infiltration, runoff and evapotranspiration, has been coupled with a GIS (GRASS) in order to evaluate the expected effects of climatic changes and land use management on the water balance, particularly drainage below the root zone of crops. The approach was first validated by pluriannual observations obtained on an agricultural watershed close from Grenoble, in the South East of France. Preliminary results show that at the scale of a watershed the doubling of CO_2 will probably have a very negative aspect upon ground water resources, by the combination of decrease of recharge and increase of irrigation requirements. In consequence, impacts of various alternative land uses on the water balance have been simulated in order to determine the most appropriate agricultural practises in view of a sustainable development. This research was done in the frame of an EU-DGXII Programme (ECRASE)

RAINFALL GENERATOR FOR SOUTHEASTERN CENTRAL AFRICA

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The waterbalance model 'Replenish' is developed to assess the contribution of evaporation to rainfall through moisture feedback, for the region of Zambia and Zimbabwe. Moisture fluxes are modelled with an advection dispersion equation. Rainfall is generated if the actual moisture content exceeds a stochastically generated carrying capacity. Other, more established, stochastical models also use the randomness in the occurrence of rainfall and in rainfall sizes for their frequency distributions. Some stochastical rainfall generators have combined the frequency distribution for the rainfall sizes and the probability of a shower. These rainfall generators use an autocorrelated parameter as a measure for the rainfall size. If this autocorrelated parameter is smaller than zero, the rainfall is zero. This principle is derived purely from frequency distributions of rainfall sizes and has no physical background. The present model, however, is physically based. It uses the frequency distribution of the precipitable water at the upstream boundary and the frequency distribution of the carrying capacity of the atmosphere as a function of space. The 'Replenish' model represents the relation between precipitable water data from upper air stations and rainfall data around the upper air stations in Southeastern Central Africa very well.

DETERMINATION AND ANALYSIS OF THE REGIONAL EVAPOTRANSPIRATION BASED ON REMOTE SENSING AND GIS

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The evapotranspiration (ET) is a fundamental parameter in the irrigation scheduling. The models for estimating this parameter based on punctual climatics measurements could induce considerable errors when you are working with extensive areas.
In this work the regional ET has been determined from Landsat TM satellite images calibrating a rational model for the Basin of the Guadalquivir river. The goodness of the model in a inferior spatial resolution has also been checked, aggregating the original Landsat image to NOAA-AVHRR resolution.
Subsequently, a geographical analysis of the ET with maps of crops, soils and digital elevation model have been made. Lastly, these outputs have been utilized in order to determine the areas with a better agronomy potential for the two predominant crops of the zone.

THE EVAPORATION OF PRECIPITATION AND ITS GEOGRAPHICAL DISTRIBUTION

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The evaporation of precipitation in the subcloud layer depends strongly on environmental relative humidity, then on air temperature, the precipitation rate itself and on the height of the cloud base. All these dependencies have been shown by the authors (1996) to be approximately linear. Finally the evaporation of rain differs significantly from that of snow.

Using climate data an attempt is made to estimate for selected regions from the pole towards the equator how much of the annual precipitation generated aloft evaporates before reaching the ground. The calculations are performed by employing the size distributions given by Sekhon and Srivastava (1970,1971), by solving the diffusion equation for water vapor and by assuming that all precipitation particles are in thermal equilibrium.

DERIVING SOIL MOISTURE STATUS AND EVAPOTRANSPIRATION IN THE SAHEL FROM THE PATHFINDER AVHRR LAND DATA SET.

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A modeling experiment was designed to study the effects of land cover changes on the rainfall decline observed in the Sahel since the late sixties. This experiment, conducted in the framework of an European project, aims at studying the sensitivity of a mesoscale circulation model to varying surface conditions over the Sudano-Sahelian zone (10° to 20°N, -20° to 40° E). Evapotranspiration is a key component of the interaction between the continental surface and the atmosphere and its estimation is thus a prerequisite of this study, e.g. for validation of the mesoscale model. We are presenting here the preliminary results regarding the estimation of evapotranspiration from the 1992 daily Pathfinder dataset extracted over the sudano-sahelian zone. First, the analysis of the daily Pathfinder images lead us to correct this dataset from various perturbing effects (viewing geometry, atmospheric water vapour) using simple semi-empirical models. Evapotranspiration is then derived combining two different approaches, namely the simplified relationship: $ET\text{-}Rn=a\text{-}b(Ts\text{-}Ta)$, where b depends on the surface characteristics *(NDVI)*, and the slope σ of the *Ts/NDVI* scattergrams, where σ depends on surface moisture availability. The algorithm is calibrated and validated using several existing ground datasets (HAPEX-Sahel experiment, gauged catchments). The obtained spatial and temporal patterns are finally analysed with respect to rainfall and net primary production data.

RECENT HISTORICAL CLIMATE CHANGE AND ITS EFFECT ON LAND USE IN THE EASTERN PART OF WEST AFRICA

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There are indications that rainfall decreases in West Africa and that drought periods and famine become more frequent. This may in part be a rather early expression of the effect of global warming but it is very likely that local factors such as drastic changes in land cover due to expanded cultivated area, as required by a growing population, play an important role. Before studying the causative mechanisms of climate change, it first needs to be established that climate did indeed change significantly, and if so, its nature, extent and magnitude has to be quantified. To this effect time series of annual rainfall (1950-1992) for 42 synoptic climate stations in eastern West Africa, covering 5 countries, were analyzed. The data were subjected to several statistical tests for the entire time series and parts thereof. The outcomes were interpolated in a GIS environment to assess the spatial pattern of change. The time series and spatial analysis show that climate change is indeed significant in the northern part of the study area and that the degree of change shows a spatial pattern which can be related to the weather system in combination with topographical conditions of the land. A remarkable feature is that the change in rainfall is not a gradual one, but consists of a trend break with zero trend before and after the break. This is unexpected because it might imply that causal factors have to be sought under those that do not change gradually. The year of occurrence of the break varies in time, again according to a geographic pattern. The effect of reduced rainfall on the length of the growing period (LGP) has been calculated on a year-to-year basis before and after the trend break. The effect of shorter growing periods on potential crop yield and its variability has been quantified. The analysis shows the serious implications for land use in the semi-arid region of West Africa.

HS8.2 Climate change and water resources management

Convener: Behr, O.

THE TENDENCY OF DECREASING OF THE WINTER WATER RESOURCES IN THE BALCAN REGION

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The variability of winter mean water resources (precipitations and discharges) as observed at the longest observing gauging stations in Romania is examined. The results are placed in the context of the droughty periods in the Balcan region.
Almost all stations exhibit a systematic decrease ("downward shift") at about 1969 in precipitation and 1970 in discharges. This systematic change is shown to be real and not an artificial fact due to the inhomogeneities in the precipitation or discharges data in a two step procedure. First the Pettitt's statistic is analysed for the two kind of series and this is related of the European-scale sea-level air-pressure field through a Canonical Correlation Analysis (A. Busuioc, H. Von Storch, 1995).
The decreasing of water resources during winter is evident. We cannot assert whether the dynamics of these changes in the large-scale circulation found in regional studies over Romania and Balcanic part of the Danubian countries are natural fluctuations of the climate system or are determined by the external forcing, but the results in continuos decreasing of water resources during winter is an incontestable fact.

CLIMATE VARIABILITY AND CHANGE AND WATER RESOURCES IN BULGARIA

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Climate variability and expected change in Bulgaria were investigated. In North Bulgaria a trend of warming on a small scale was found, however there was a trend of cooling in South Bulgaria. Precipitation varied considerably from year to year during this century. The results suggested that there was a decreasing trend in precipitation from the end of 1970s. Precipitation has been below a 30-year average for 11 of the last 13 years of investigation. In fact, from 1984 to 1993 the country experienced more than 5 years of drought conditions of various intensities depending on location. Using GCM outputs climate change scenarios for Bulgaria were created, analyzed and compared with the observed current climate trends According to the GCM 2*CO_2 climate change scenarios annual temperatures in Bulgaria are predicted to rise by 4.0°-4.4°C. Precipitation is expected to increase during the winter and to decrease during the warm half-year. Due to decreasing of precipitation during growing season of spring agricultural crops a decreasing of crop yield could be observed. That is why a new management of water resources for irrigation is extremely necessary. Using a decision support system for agrotechnology transfer (DSSAT) numerical experiments were carried out in order to choose the most appropriate strategy in crop irrigation under warmer and drier climate. Different adaptation strategies regarding mitigation of vulnerability of water resources in the country due to climate variability and change were also considered in the study.

DISAGGREGATION OF GCMs OUTPUTS TO PREDICT THE EFFECT OF DOUBLING OF CO2 ON GROUNDWATER RECHARGE

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In our actual stage of knowledge, the General Circulation Models (GCMs) are probably the best available tools to provide estimates of the effects of raising greenhouse gases on rainfall and evaporation patterns, but only at a large scale. We suggest here to adapt a GCM to local scale through parameters estimation coupled with a weather generator. The basic assumption is that GCMs do provide pertinent variations of climate characteristics induced by a change of scenario. A local weather generator based on the knowledge of simple climate statistical properties was developed. Measured local climate data was used to generate a base scenario for rainfall and potential evapotranspiration. The changes induced by a doubling of CO2 predicted by the GCM were used to modify the statistical properties of the climate data and to generate a perturbed scenario. The obtained scenarios were then used with a distributed, physically based comprehensive hydrologic model to evaluate the impact of CO2 doubling on groundwater recharge. Results obtained for a watershed in S.E. France indicate that the doubling of CO2 will result in an increased water deficit during summer months and long term depletion of groundwater resources. This research was done in the frame of an EU DG XII Programme (ECRASE).

DISAGGREGATION OF PRECIPITATION TIME SERIES FOR IMPACT ASSESSMENT OF CLIMATE CHANGE

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Development of downscaling methods are essential in the estimation of regional effects of a climate change; assessment of regional impacts are especially important regarding precipitation due to its crucial importance in water resources. The Method of Fragments (Srikanthan, 1982) was adapted to disaggregate accumulated precipitation totals. Fragments are obtained dividing each set of observed disaggregated values by the corresponding observed aggregated total. Each fragment is then assigned to a class computed from ranked time series of observed aggregated values. Three runs of the model, to generate synthetic values of rainfall, were performed using fragments from class K, fragments from classes K-1, K and K+1 and fragments from classes K, K+1 and K+2. The model was used to generate 53 years of monthly precipitation totals for Viana do Castelo, from the corresponding annual totals, and 22 years of daily precipitation totals for Coimbra, from the corresponding 264 monthly totals. The method works reasonably for year to month disaggregation, where correlation coefficients are of the order of 57 %, in the 2nd and 3rd runs of the model. The seasonal cycle is well simulated. For the month to day disaggregation the correlation coefficients are much smaller but other indexes as mean absolute error and root mean square error remain as good as before. In all model runs the hit rate is always higher than 50%. The 2nd run, seems to give, in general, the best results. The method is applied to climate change scenarios produced by the Hadley's Center new set of experiments.

CLIMATIC VARIATIONS AND WATER RESOURCES: THE CASE OF THE RIVER NESTORE (CENTRAL ITALY)

W. Dragoni, D. Valigi & L. Mastrorillo (Perugia University, Italy)

For the Mediterranean area GCMs predict an increase in temperature of up to 3 °C in the next 50 years; the precipitation forecast ranges from +30% to -30% compared to present average values. Actually the statistical analysis of some long sets of data of stations located in Central Italy shows a decreasing trend in rainfall, with a maximum gradient of around 3 mm/year. For the temperature, an increase of around 0.5 °C in 100 years is also present. An analysis has been made of the possible effects of climatic variations on the water yield of the River Nestore (tributary to the River Tiber). The data available (1986-'92) for the R. Nestore have been used to calibrate a rain-runoff model. The basin's water yield for the period 1934-'92 was reconstructed using the calibrated model. Water yield for the period 1993-2050 was computed increasing the temperature and decreasing the rainfall of the 1934-'92 set of data. Four climatic scenarios were assumed, in which the average yearly temperature increased by 0.5, 1, 1.5 and 2 °C. For each increase in temperature, three simulations were carried out, applying a 5%, 10% and 15% yearly average reduction in rainfall. The simulations indicate that the worst scenario could feature a reduction in water yield of up to 40%. The climatic trends actually detected point to a reduction of about 18%. This amount is rather worrying in an area already suffering from a shortage of high quality water.

INTEGRATION OF FOREST STAND PHYSIOLOGY WITH INTERCEPTION, SOIL WATER STORAGE, AND PERCOLATION: EVALUATING POTENTIAL CLIMATE CHANGE EFFECTS

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Climate change effects on key ecosystem parameters, e.g. CO_2 uptake, transpirational water loss, soil water storage, and percolation to ground water have been studied with a model hierarchy based on intensive experimentation in spruce forests. The BIGLEAF model for spruce, which implicitly includes up-scaled biological information from a nested hierarchy of process-based models (considering non-linearities, interactions, sensitivity to stress and seasonal changes in forest gas exchange), has been linked to the soil in the model PROXEL. PROXEL has been validated, based on three relatively long-term data sets of spruce forest stand water balance. Empirical (but process-based) coupling factors between soil water and canopy conductance were determined. Using this coupled SVAT model, the effects of doubling atmospheric CO_2 on CO_2 uptake and stand water balance were obtained for the model validation sites in the Vogesen and Fichtelgebirge. Results indicated initial reduced canopy conductance due to elevated CO_2 during early season with wet soil, but greater conductance at the end of a long drought due to the greater effect of savings in soil water than the direct effect of elevated CO_2 on stomata. The implications for forest function may be that growth and production will be enhanced, especially with high nitrogen availability, and percolation will increase at wet sites. Future work must consider long-term changes in forest leaf area index.

STRATEGIES OF WATER RESOURCES MANAGEMENT IN THE REPUBLIC OF MOLDOVA

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In the frame of the NATO Programme "Science for Stability" a new project "NATO MOLDOVA-Waters - Methodologies for Water resources Development and Management in Moldova" is initiated. The aim of this project is to assure the rational untilization and the protection by introducing a continuous monitoring of water quantity and water quality. As a main problem which is identified and needs appropriate measures, a tendency of decreasing water levels appeared in the biggest rivers of Moldova.

CLIMATE CHANGE IN MOLDOVA DURING THE LAST 90 YEARS

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According to the available historical records, within the last thousand years 137 severe droughts occurred in Moldova. From the 19th century onward an increase of the frequency of drought years occurred. The increase became very obvious in the 20th century. During the last 90 years around 47 severe and long droughts have been observed. These changes are climatologically based, but are additionally enhanced by a decrease of the forested area, by the drainage of swamps and by an increase of t he arable area up to 79 %.

IMPACTS OF CLIMATE CHANGE ON THE HYDROLOGICAL REGIME OF THE RHINE RIVER

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The Rhine river is economically the most important river in Central Europe with a large diversity of hydrological regimes from the Alps to the lowlands before the river discharges into the North Sea. Catastrophic floods in 1994 and 19995 and extended low flow periods in previous years have demonstrated the possible vulnerability of basic river functions under climate change conditions. In face of the climate change the providence of advice to decision-makers in water resources management therefore is necessary. This requires the assessment of possible changes in the hydrological regime of the Rhine river and selected subcatchments. By the use of climate change scenarios and hydrological models suitable for the diverse hydrological regimes, changes could be simulated. From the simulations a number of impacts can be identified, which are common for all sub-basins of the Rhine basin and the entire Rhine basin itself. The modification of the snow cover (duration, regional distribution, depth, probably also the structure of the snow cover) is the most important effect of climate change for hydrology and as a consequence for sectors of economic importance. Changes in the hydrological regime of the Rhine are so large, that long-term water management strategies should consider the effects of climate change even if the scenario uncertainties are acknowledged. Balancing the required actions against economic costs and the uncertainties in the climate change scenarios, a "Policy of no Regret" is recommended. Amongst the recommendations are the naturalization of river-beds and flood plains for flood mitigation, increased flexibility of inland navigation to respond to changes in the lowflow regimes, and the improvement of water resources management strategies including hydropower generation, irrigation and groundwater recharge.

THE SIMULATION OF CLIMATIC RUNOFF REGIME CHANGE USING HBV RAINFALL-RUNOFF MODEL

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The runoff regime changes were simulated using rainfall-runoff model HBV in Ondava river basin. The simulation is based on temperature and precipitation changes scenarios according to five global circulation models (CCCM, GISS, GFD3, OSU and UKMO). HBV model was calibrated by measured series of daily precipitation totals, mean daily temperatures and mean daily discharges of 5 hydrological years 1986/87 - 1990/91. For the estimation of the long-term mean monthly potential evapotranspiration 4 methods were tested. The Thornthwait method based on mean monthly temperatures was chosen for the estimation. The sensitivity of the HBV model on increase of the input temperatures and precipitation was tested, too. Runoff simulated by HBV model with input data adopted according to circulation model CCCM is by 7.1 % smaller than in recent conditions. The increase of runoff (0.67 %) was simulated using UKMO scenario for adoption of the input data.

VARIATION OF THE SNOW COVER CHARACTERISTICS IN MOUNTAIN REGION OF BULGARIA

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The snow cover in Bulgaria is a seasonal phenomenon. It has not only climatological but also hydrologycal and to a certain extent economic significance. Above 1200 m the period of its existence increases with altitude up to eight months. Lately a growing demand of snow cover data observed during the recent decades was experienced. This interest has been aroused by more and more frequent droughts, occurred in the region.

The aim of the study is to describe the main features of variation of some important characteristics of the snow cover pattern in the period of 1935/6-1995/6. The basic data consists of number of days with snow cover, the date of the first and the last day with snow cover and max. snow depth. The snow cover variations are studied using statistical methods. The presence of some forms of trend in data are examined by the Spearman and Mann-Kendall rank statistics.

TEMPORAL VARIATION OF THE DAILY EXTREME HIGH PRECIPITATION IN THE LOWER DANUBE BASIN

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C. Boroneant (National Institute of Meteorology and Hydrology, Bucharest, Rumania)

This study presents an examination of the daily precipitation above 30 mm during the period 1931-1995. The data base consists of data from 10 stations of Bulgaria and Romania. Variability and tendency of the occurrence of the daily high and extreme high precipitation were estimated using statistical methods. A question arises, whether any change of extreme meteorological events, the daily extreme high precipitation amounts, ensue as a result of the global climate change.

APPROACH OF WATER RESOURCES MANAGEMENT UNDER CLIMATE CHANGE

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Existing methods of hydrological computations for water resources management is based on the conception of stationarity and homogeneity of hydrological sample. Climate change, man's impact and other factors lead time series of water characteristics to non-stationary and non-homogeneous conditions and do not allow to use the existing approach. Therefore a new approach and methods have been developed for water resources management in these changing conditions and they include determination of simple homogeneous components from complex common process (which connect with climate change, direct man's impacts on the watersheds, etc.), modelling and extrapolation of every homogeneous components on the period of water projects, new rules and method for determination of empirical probability, return period for the particular projects and methods for the estimation of computed value errors. Different case studies have been given for different regions (the Danube River, the Nile River, some river basins in Russia) as well as for different runoff characteristics: low-flow, maximum and annual runoff.

SPATIAL AND TEMPORAL RAINFALL VARIABILITY: A TREND SERIES ANALYSIS APPLIED TO THE MEDITERRANEAN COAST OF SPAIN.

De Luis, M., Raventós, J; González-Hidalgo, J.C.
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The effect of climate change on ecosystem stability and water resources will depend not only on the trends in rainfall concentration but also from their temporal variability. We have studied trends in the variability of an area caracterized by slight to extreme desertification risk and limiting water resource: The Region of Valencia (Spain)
In particular we have used rainfall data from 100 pluviometric stations over the period 1961-1990. The main results of these analyses are:
(1) Variability in annual rainfall volume increased in most stations . This trend resulted from increased variability in autumn precipitation. The variability in winter rainfall decreased inland and highly increased in the coastal areas.
(2) Variability in rainfall concentration increased inland, and decreased in the coastal zone where Atlantic and Mediterranean fronts colide.
We discuss these results considering published rainfall trends in other Mediterranean areas and predicted trends from model simulations, and we identify potencial effects on ecosystem and water resource.

SPATIAL AND TEMPORAL RAINFALL CHANGES: A TREND SERIES ANALYSIS APPLIED TO THE MEDITERRANEAN COAST OF SPAIN.

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Sánchez, J.R., Cortina, J.
Dept. d'Ecologia. Univ. d'Alacant. SPAIN

Changes in rainfall amont and concentration.will be one of the key factors of climate change affecting ecosytem stability and water resources.
We have studied trends in precipitation in an area characterized by slight to extreme desertification risk and limiting water resources. In particular we have carried out a trend analysis of annual and seasonal rainfall volume and analyzed changes in the Precipitation Concentration Index (PCI) from 100 pluviometric stations for the period 1961-1990.
The main outcomes of the study are:
(1) There is a significant general decline in annual rainfall volume. This decrease resulted from reduced Autumn precipitation. Winter and Spring rainfall increase in most stations.
(2) PCI increase inland, and decreased in the coastal zone where Mediterranean and Atlantic fronts colide.
We discuss these results considering published rainfall trends in other Mediterranean areas and predicted trends from model simulations, and we identify potencial effects on ecosystem and water resource.

ESTIMATION OF THE REGIONAL CLIMATE CHANGES INFLUENCE ON FLOOD RUNOFF IN THE RIVERS OF THE UKRAINIAN CARPHATIANS

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Some results of the analyses of the influence of climate changes on the flood runoff in the Ukrainian mountain region are presented. The investigation refers to 12 rivers within the basins of the Dnister (eastern Carpathian slopes) and The Tissa (western slopes) The catchment areas vary from 400 to 2000 km^2, and represent a low level of anthropogenic influence on the water regime. The data series refer to the period 1946-1992. The analyses show a statistically significant increase of the mean annual discharges since 1975 of about 12-25%, whereas the coefficient of variation decreased by 4-12%. The changes in the hydrological characteristics are due to a modification in the meteorological regime for the period 1975-1992. The modification is characterized by an increase of summer precipitation (9-30%) and winter precipitation (2-8%) and an increase of winter air temperature (0.3-0.9°), whereas summer temperature decreased slightly (0.1-0.4°). As a consequence of the enhanced precipitation, soil moisture increased, thus favouring a reduction of runoff losses during flood formation and a corresponding increase of the frequency of very high floods, especially during summer. In particular, during the last 6 years 6-10 floods annually occurred on the Carpathian rivers. The floods on Dnister in May 1989, and on the Transcarpathian rivers in October 1992, November 1992 and December 1993 were severe hazards causing significant economical damages. Thus, climatic trends should be taken into account for creating a new methodology for runoff calculation.

SIMULATION OF REGIONAL PRECIPITATION AND TEMPERATURE USING ATMOSPHERIC CIRCULATION PATTERNS OUT OF GCM'S WITH A STOCHASTIC WEATHER GENARATOR MODEL

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To investigate consequences of climate change on the waterbudget towards a smaller catchment, it is necessary to know the change of local precipitation and temperature. GCM's cannot provide regional climate parameters yet, because of their coarse resolution and imprecise modelling of precipitation. For this reason downscaling of precipitation and temperature have to be carried out from the GCM-grids to a small scale of a few square kilometers. Daily rainfall and temperature are modelled as processes coupled to atmospheric circulation for a small catchment in Germany. Rainfall is linked to the circulation patterns using conditional probabilities. Temperature is modelled using a simple autoregressive approach, conditioned on atmospheric circulation and local areal precipitation. The model uses the classification scheme of the German Weather Service and a fuzzy rule based classification using the subjective definitions of the previous classification scheme. The stochastic weather generator calculates rainfall and temperature in the past (observed pressure fields) and the future (GCM-pressure fields); calculated values agree fairly well with historical data. Results for different GCM-scenarios will be shown.

CHANGES IN MEANS AND VARIABILITY OF RIVER FLOW IN THE TISZA BASIN: SCENARIOS AND IMPLICATIONS

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Hydrological characteristics of rivers in the Tisza Basin exhibit high variability in time. Hence, potential climate changes may be critical for the management of water resources in the region. Three aspects of the given problem are tackled: First, the derivation of the regional climate scenarios is given that contains (i) three IPCC'96 global alternatives; (ii) a statistical method to connect the global temperature changes to the regional climate elements; (iii) a regional energy- and water-balance model to interpret, complete and validate the statistical results; (iv) the geographical analogy approach to downscale the seasonal projections in time and (v) a stochastic weather generator to simulate daily weather series. Second, quantitative estimations of changes in runoff are presented by applying a conceptual model with modular structure to route the resulting daily meteorological input. Beside a versatile snow accumulation and snowmelt module, the core of the model is the GAPI rainfall-runoff model extended with a module of channel routing. Projected changes in the runoff statistics are compared with those, previously published for the same region. In third part implications of changes in the low flow and flood duration and also of the robust part of runoff distributions will be considered, basically pointing out the needs for additional freshwater sources and storage capacities in the region.

COMPARISON OF LONG-TERM ANNUAL PRECIPITATION AND DISCHARGE IN THE SAVA RIVER BASIN WITH GLOBAL ATMOSPHERIC CIRCULATION

K. Pandžić, D. Trninić (Meteorological and Hydrological Service, Grič 3, HR-10000 Zagreb, Croatia)

The climatic variability of annual precipitation in the Sava river basin was analyzed using five weather stations for the period of 1891-1990. The influence of this variability on the annual discharges for three hydrological stations in the Save basin for the period 1931-1990 has been identified. A pronounced correlation between the anomalies of the analyzed parameters and the European-North Atlantic sea-level air pressure anomalies has been detected. As a result, future scenarios of the global atmospheric circulation models (GCMs) can be used for the estimation of the climatic parameters in the Sava river basin. This can be done by means of statistical or deterministic methods.

CLIMATE CHANGE IMPACT ON WATER MANAGEMENT IN THE NITRA BASIN (SLOVAKIA)

P. Petrovič (Water Research Institute, NAb. gen. Svobodu 5, 812 49 Bratislava, Slovakia)

The study presented is dealing with the evaluation of the expected hydrological balance of the Nitra river basin for the period of 2030±15 years. The evaluation is based on a tuned mathematical model of the hydrological balance of the Nitra river basin, where the basin is substituted (from the point of view of air temperature and humidity) by the point of vertical gravity of the basin. It is assumed that the reference time period of 1951-1980 still is undisturbed by climate change, and that the obtained model parameters will not change within the time under consideration (65 years). Monthly time steps are used. The scenarios of possible climate change were prepared for the whole Slovakia by the Slovak Hydrometeorological Institute, and the recommended seven possibilities (CCCM, GISS, GFD-3, WP-A, WP-B, SD-A, SD-B) were processed. As a result, significant changes are to be expected in the yearly runoff distribution, especially in the summer half year. The future runoff is expected to increase only in the three winter months (due to lower snow accumulation), whereas it is expected to fall below 70% of the present runoff for more than 4 months in summer. 90 % of the eventual increase of precipitation is consumed for an increase of actual evapotranspiration, so that the rise in the runoff yearly total then seems to be negligible. Future actual evapotranspiration and soil moisture data are discussed. The obtained results should help to eliminate the expected negative impacts.

CLIMATE CHANGE IMPACTS ON RESERVOIR OPERATION

M.A. Mimikou and E.A. Baltas (Department of Water Resources Hydraulic & Maritime Engineering, National Technical University of Athens, 5, Iroon Polytechniou 157 80 Athens, Greece)

This study examines the assessment of climate change impacts on some critical water management issues, such as reservoir storage and hydroelectric production in northern Greece on a regional basis (catchment scale). Initially, a monthly physically based water balance model was applied to estimate runoff values at the entrance of a large multipurpose reservoir (Polyfyto reservoir) under different climatic change scenarios. Two equilibrium scenarios (UKHI, CCC) referring to years 2020, 2050 and 2100 and one transient scenario (UKTR) referring to years 2032 and 2080 were implied. By using these scenarios, the sensitivity of the risk associated with the annual hydroelectric energy production of the Polyfyto reservoir in northern Greece has been evaluated under conditions of altered runoff. It is shown that the operational characteristics of the reservoir designed and operated under current climatic conditions are, in general, affected by the climate change scenarios examined. Increases of the risks associated with the annual quantities of energy production have been observed, particularly under the UKHI and the UKTR scenarios. In order to maintain existing energy yields at tolerable risk levels, increases of storage volume are needed.

THE PREDICTED EFFECT OF CLIMATE CHANGE ON AQUIFER RECHARGE FOR THE BISAGNO BASIN

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The predicted effect of climate change based on GCM results was used to evaluate possible variations in aquifer recharge using a distributed hydrological model at basin scale. The model, developed as an aid to phreatic water management under variable climatic conditions, is suited to small basins in mountainous Mediterranean coastal areas and uses geomorphologic scaling relationships for surface and hillslope routing features. Simulations have been carried out for two climate scenarios: the first characterized by a rainfall process corresponding to present day CO_2 concentration and the second by a modified rainfall process corresponding to the doubled CO_2 concentration. The statistical parameters of the present day rainfall process scenario have been calculated from a 30 years time series of measured data while the statistical parameters of the modified scenario have been inferred from the GCM simulations. The effect of modifications in the seasonal distribution of rainfall and the related variance proved to be relevant to climate change impact studies on aquifer recharge for the case study investigated. The work described in this paper was developed within the framework of the ECRASE project of the EC Environment programme.

THE ANALYSIS OF FLOW VARIATION IN THE VELIKA MORAVA CATCHMENT

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D. Lekić, K. Canić (Federal Hydrometeorological Institute, Birčaninova 6, 11000 Belgrade, Yugoslavia)

This paper presents the results of the research of flow characteristics provoked by climatic factors. The research is done for the Velika Morava catchment. The Velika Morava is a right tributary of the Danube, comprising a total area of approximately 38 000 km^2. The assessment of flow variation is given on the basis of a relationship between the tendencies in climatic factors and those in surface runoff.

THE REVIEW OF POSSIBLE CHANGES IN PRECIPITATION AMOUNTS IN THE TERRITORY OF YUGOSLAVIA FOR THE NEXT THREE DECADES

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O. Jovanović (Federal Hydrometeorological Institute, Birčaninova 6, 11000 Belgrade, Yugoslavia)

There are numerous methods for the analysis of further climate change and forecast, from methods of analogy to numerical models. This paper presents the review of possible changes in precipitation amounts in the territory of Yugoslavia for the next three decades.
The review of the existing results in assessing precipitation, from global to regional results for the territory of Yugoslavia was made using different literature (G.V. Gruza, 1994). The possible changes in precipitation amounts in the territory of our country, using the method of analogy, were calculated in Federal Hydrometeorological Institute of Yugoslavia.

CLIMATE CHANGE EFFECT ON AGRICULTURAL WATER DEMAND IN RUSSIA

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Climate change will have an extensive effect on water demand through changes in supply, year-to-year differences in availability, water quality and intra-year distribution. Because irrigation water demand is a significant use of water, the planning of irrigation development is closely related to the planning of water resources systems. In any empirical study of water demand forecasting, there is a variety of models to choose from. Optimization models allow for a detailed consideration of the behaviour of economic agents under a changing environment. Such models can be applied at an enterprise at regional or national levels. Socio-economic strategies have been created on the basis of climate scenarios. Scenario-based indices of climate-agricultural-water resources systems are transformed into social and economic strategies. To cope with this objective, a broad set of alternatives was analyzed, and different sustainable solutions have been identified. The report refers to the estimation of water requirements for the irrigation systems in the semi-arid zone of Russia. The problem of water supply-demand integration is central in this work. Agricultural systems adaptation to climate change is considered. Climate and economy effects on system management strategies are compared.

ANALYSIS AND DETECTION OF RAINFALL SERIES TRENDS IN THE EBRO VALLEY (SPAIN)

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J. L Marcos, A. Vega, A. Castro, R. Fraile (Applied Physic Dep. University of Leon. Spain)

Broad tracts of the Iberian Peninsula suffer from scarce and variable precipitation. In many cases, as in the Ebro Valley, these correspond with areas where agriculture is highly developed, where there is a high level of production and production quality, and where, as a result, alterations in rainfall patterns can have very negative economic repercussions. Using the monthly precipitation figures recorded between 1961 and 1990 in 58 observatories located along the length of the R. Ebro, the frequency of repetition of rainfall cycles was determined for the region, based on Fourier analysis.
The Kendall test was used to analyze the trends, beginning in each case with the year in which a trend began to be negative, and statistically siginificant. The anomalies uncovered in the data from certain observatories correspond geographically with an area of the Ebro Valley threatened by desertification, and suffering severely from soil erosion. These statistically signficant negative trends in data from some observatories are to be detected, principally, in the autumn period, and can be shown to have commenced towards the end of the 1960s.

IMPACT OF THE CLIMATIC CHANGES ON THE WATER RESOURCES

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For the assessment of the climatic change impact on the water resources, two scenarios are considered: scenarios 0 consisting in the simulation of the runoff over a historical period by means of a mathematical model by considering the measured inputs and scenario 1 simulating the runoff over the same period, considering the inputs of the model as modified, determined in the hypothesis that the CO_2 amount in the atmosphere is doubled. The used mathematical model is a rainfall-runoff conceptual model made of three main components: water release from the snow cover, determination of the effective rainfall amount and the calculation of the discharge hydrograph. The mathematical model was applied for three representative basins located in mountain, hill and plain zones from Romania. The results enable us to estimate the impact of the climatic changes on the water resources at annual level and, also, during the year (monthly discharges, floods and maximum discharges).

ON THE INFLUENCE OF EXPECTED ANTHROPOGENIC CLIMATE CHANGE ON HYDROLOGY AND WATER RESOURCES IN LARGE RIVER SYSTEMS

I.A. Shiklomanov, V.I. Babkin, V.Yu. Geogyievsky, A.L. Shalygin (State Hydrological Institute, 23 Second Line, St. Petersburg, 199053 Russia)

1. Cited are the results of studies on revealing river catchments response to the global and regional climate change for the resent 10-15 years in Russia.
2. The analysis is made of methodological approaches to estimation of the expected anthropogenic climate change effects on hydrological characteristics and water resources under different physiographic conditions.
3. The analysis is made of the results of estimating the effects of expected global warming on hydrology and water management in the basins of the largest river systems in the former USSR territory based on various climatic scenarios.
4. The typical physiogeographic regions are characterised by the data on potential changes in total water resources with adopting the future climate scenarios based on various GCMs and paleoclimatic analogues.
5. Discussed are the problems of water management, water supply, designing water management structures in different natural zones under the conditions of non-stationary climatic situation.

LONG-TERM AND SHORT-TERM HYDROCLIMATIC VARIABILITY IN SCOTLAND AND NORTHERN IRELAND

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This paper examines hydroclimatic variations in rainfall and runoff in Scotland and Northern Ireland over a variety of timescales to ascertain whether the apparent hydrologic extremes in the early 1990s are indicative of climate change, or merely within the range of variability witnessed within the period of record. Available long-term records (back to 1930 for runoff and 1861 for rainfall) are compared with more abundant short-term records in order to establish the hydroclimatic significance of present day conditions. Trends, periodograms and peak over threshold analyses are used to establish the nature of any changes in the variability of rainfall and runoff. Trends in Lamb's synoptic weather types are also assessed in order to identify the potential driving mechanism. The results reveal an intensification of the rainfall gradient (wetter west, relatively dry east) across Scotland over the period 1961-91, much of the additional rain being recorded in the winter months in the west. Coupled with this is the finding that the 1960s and most of the 1970s were "flood-poor" whereas the late 1980s and early 1990s have proved to be "flood-rich". It is suggested that these results will be of major significance to water resource managers in Scotland concerned with setting future water quality standards, providing flood defence and the generation of hydro-electric power.

REGULAR ALTERNATION OF HIGH AND LOW STREAMFLOW PERIODS IN THE RIVER BASINS OF THE CARPATHIANS

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The structure of the long-term runoff time series of the Tisza and the Dnister basins can be explained by a combination of high and low streamflow periods and by cyclical components. The cyclical components with periods of about 3-4 and 7 years are detected in the high streamflow part of the series. During low flows, they are not present. These natural phenomena can serve as a basis for runoff prediction for the next years, associated with a certain level of probability. The predictions are composed of a sample mean and probable fluctuations. A similar decomposition of the time series could be of methodological value for other river basins, too.

HYDROLOGICAL DROUGHT MONITORING OVER THE SOUTH-WEST REGIONS OF ROMANIA USING GIS TECHNIQUES

Gheorghe Stancalie, National Institute of Meteorology and Hydrology, Bucharest, Marie-Jeanne Adler, Simona Catana, Corina Alecu, National Institute of Meteorology and Hydrology, Bucharest, Romania

The increase of the aridization trends under the conditions of the droughts having affected large areas of Romania during the last two decades, has determined the initiation of a pilot pilot projet for the evaluation and surveillance of water resources by remote sensing and GIS tecniques. The area of interst corresponds to the Plain of Oltenia, geographical subunit in the south - west of the Romania. The paper emphasizes the advantages obtained by means of remote sensing and GIS technics through:

- the definition of certain data bases made of observations modelled by spatial representations;
- the handling and preparation for rapid acces of large amounts of data;
- the possibilities to assembly files and to analyse the spatial characteristics of the hydro-meteorological data;
- the facilities for updating data and emphasising the temporal modifications;
- the acquisition of complex information faciliting the study and substantiation of response strategies for the diminishing and prevention of the hydrological drought effects and the reconstruction of the environmental conditions.

UPSCALING PROCEDURE FOR THE ASSESMENT OF THE POTENTIAL IMPACT OF CLIMATE CHANGE UPON WATER RESOURCES

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The assessment of the impact of the climate change, due to the double amount of CO_2 in the atmosphere, on the hydrological resources has been performed in three large *analyzed basins*. These basins (Siret, Argeş and Târnave) are located in main geographical regions of Romania and they are different from the actual water uses point of view. A rainfall-runoff mathematical model was applied on three small *pilot basins*, representative for mountain, hill and plain zones which are found in the selected analysed basins. Furthermore, the simulation of the runoff in the case of medium or large size basins is difficult to carry out due to the use of a complex procedure which implies both the averaging of the meteorological data over the basin and an increasing of the number of the model parameters. The conceptual mathematical model, which is a reservoir type model, was applied in two cases: stationary regime ($1CO_2$ scenario) and modified regime ($2CO_2$ scenario). The river flow at the outlets of the pilot basins simulated by the model for both scenarios are then transferred to several river sections in the analyzed basins by an upscaling procedure.

FLOODS STUDY OF POLISH RIVERS BY THE IDT SOFT TOOL

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The subject of the study are annual peak flow discharges of Polish rivers. The whole available set of long uninterrupted time series from rivers not very much affected by artificial water storage was taken for analysis. It consists of 37 series covering the period 1921-1990. The series have been processed by the Identification of Distribution and Trend (IDT) soft tool. Its out-come is presented and discussed. Despite of our expectations which are based on antropogenic changes in drainage basins, it is the negative sign of time trend which was found in the first moment or in the two first moments in the superior number of time series. The decreasing trend may be effect of presumable climate changes. According to the AIC goodness-of-fit test the trend is significant in 18 of 37 series. Therefore nonstationarity of flood process shall be considered in the hydraulic design. Considering the series as stationary it is the two-parameters log-normal distribution which shows according to the AIC the best fit to the data in most cases. The second in turn it is the Pearson III type distribution with lower bound as the parameter.

ASSESSMENT OF BASIC ADAPTATION STRATEGIES FOR WATER RESOURCES MANAGEMENT UNDER CLIMATE CHANGE IN SLOVAKIA

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Thirty watersheds and regions with existing and/or planned water resources utilisation schemes (reservoirs for drinking water supply, flow augmentation and hydroenergetical use, carstic areas with water wells, areas with irrigation reservoirs and regions with agricultural production etc.) covering a variety of hydrometeorological conditions have been selected as representative areas for the climate change impact study. Several models relating runoff forming factors to the long term mean annual runoff have been tested to simulate the impact of various climate change scenarios in a GIS based simple water balance model. The uneven spatial distribution of water resource surplus indicates, that areas in the southern parts of mid and east Slovakia could be especially vulnerable to climate change. Basic boundary conditions for the future utilisation of the water resources of Slovakia based on the prediction of the industrial, energy related, agricultural and the domestic water use and expected economic growth are discussed. Adaptation strategies for the long term planning and management of water resources in Slovakia under uncertainty are outlined. Proposed actions with the aim to eliminate the effects negative tendencies, which will be necessary on national, regional and local level are listed.

CLIMATE VARIATION OR CHANGE? (WITH PARTICULAR REFERENCE TO THE UMGENI)

A.J. Tollow (ManTech, Box 684 KLOOF 3640, KwaZuluNatal, South Africa)

South Africa has a very variable climate and has recently experienced a number of severe droughts and floods in the last sixteen years. These events have tended to act as a mask when trying to determine any long term trend in the data. The region as a whole has a less predictable climate than similar locations in the Northern Hemisphere. In addition data tends to be sparse. Although in South Africa there is an efficient data collection service, regions, by comparison with Europe are much larger and less densely covered with rainfall and flow measuring stations. Heavy falls tend to be more extreme. For example in September 1987 the area where I live in the Umgeni Catchment recorded 1 000 mm (the average annual rainfall) in three days. Resources planning takes into account some of the extreme variations. Measures that are being taken to ensure water availability under these conditions could also apply, to some extent, those of climate change. What is more daunting is the increase in population and the increasing demand for water. One of the ways of making existing resources go further, that is being applied in South Africa is by trying to reduce water consumption by way of managing the demand by price. There is currently research progressing on the use of water in industry in which there are proposals by which they reduce their demands. Some of the techniques used in South Africa have a world wide application since it must remembered that in the one Country the climate ranges from desert to well-watered regions.

CLIMATE CHANGE ON THE TERRITORY OF UKRAINE AND BYELARUS AND ITS INFLUENCE ON RIVER RUNOFF

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The long-term observations of air temperature and precipitation as the main climatological characteristics give a judgement about the most significant changes that took place in the territory of Ukraine and Byelarus. For the period 1886-1995, an overall increase of the annual air temperature is observed, yet being more significant after 1945. Still more significant changes of the air temperature regime take place at a seasonal level. For the time period 1946-1996, the increase of the January air temperature exceeds 2,0°, whereas the July temperature decreased significantly. The precipitation did not change essentially, yet there is a small decrease in Byelarus and small increase in the South of Ukraine. Among the observed climatological changes, the decrease of summer temperature might be the most important factor influencing the river runoff. The decreasing temperature causes a correspondent decrease of evaporation by 5-10%, associated with an increase of river runoff. This result applies to the time period 1946-1995 and the largest Ukrainian rivers like Prypiat, Desna, Dniester and Dnieper, even though the Dniester and Dnieper due to extensive water intakes do not show the increase in the downstream sections. At a seasonal level, the most essential result is a decrease of the spring peak discharges, associated with a tendency of earlier occurrence of the spring flood maximum.

HS9/OA16 Hydrology of mountainous regions

Convener: Kirnbauer, R.
Co-Conveners: Braun, L.N.; Gutknecht, D.

Sponsorship: ICSI/IAHS (International Commission for Snow and Ice of IAHS)

bilities and limitations of detailed hillslope hydrological :lling

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nodelling of hillslope hydrology is considered to be of great import- for the understanding and quantification of hydrological processes ly or mountainous landscapes. In recent years a few comprehensive :ls have been developed at the hillslope scale which have resulted advanced representation of interacting hillslope hydrological pro- s and in some operational application, such as in field plot runoff, on studies and lateral flow simulation in environmental and geo- ical engineering.

is paper a comprehensive hillslope model is briefly introduced and examples for application (indicating both success and limitations) lemonstrated. The model performed reasonable calculations of Hor- an surface runoff and subsequent erosion processes, given detailed :mation of initial soil water content and on soil hydraulic conditions. vertical and lateral soil moisture dynamics can also be represented e well.

limitations of detailed hillslope hydrological modelling arise from rent points: difficulties in certain process representations (e.g. sur- crusting, unsaturated-saturated soil moisture flow, macropore flow), problems of small scale variability and data scarcity.

NATURAL AND MAN-MADE FLOODS IN THE RIVER BASINS OF CENTRAL ASIA

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The spring-summer flood comprises the main phase of the natural hydrological regime of Central Asian rivers. In this season 70-85% of the annual runoff is measured. Maximum discharges are observed during this period in the majority of rivers. The character of flood formation depends on the physiographic and hydrometeorological peculiarities of each basin; distinct combinations of the two factors could be used to explain the big anomaly of water yield or even disasters. In the past years besides floods of natural origin, the same phenomena which were strongly related to the man-made activity or management of water resources occurred. The presentation considers examples of both types.

SENSITIVITY OF DISCHARGE SIMULATIONS TO HYDRO-METEOROLOGICAL SOURCES OF UNCERTAINTY

DATIN Rachel, L.T.H.E. (UMR 5564 CNRS-UJF-INPG)
OBLED Charles, L.T.H.E. (UMR 5564 CNRS-UJF-INPG)
HELLOCO François, S.C.E.M. Météo-France.

For the purpose of operational flood forecasting, it is important to identify the main sources of uncertainties and their influence on discharge simulations. The model used in this experiment is a lumped version of TOPMODEL where the routing is based on a transfer function. The case study concerns some Ardèche subcatchments in Southern France. The first uncertainty reviewed is that of basin average precipitation when estimated from a ground network. It is due to spatial sampling and can be quantified by an estimation variance that can itself be routed through the hydrologic model. Conversely, the input precipitation can be based on radar estimation and tested in terms of discharge simulations. Finally, the Transfer Function is commonly assumed time invariant, and some time dependent ones have been tested. Our results show how sensitive are these uncertainties on discharge evaluation .

Application of the physically-based Vernagtferner mass balance model during strongly differing climatic conditions

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For Vernagtferner (Oetztal Alps, Austria), a physically-based meltwater production and runoff model was developed in the late 1970's, based on a 100m-grid DTM, and using as input hourly meteorological data and daily photographs of the glacier surface. It had been applied to the years 1978 to 1985, which were characterized by more or less well balanced budgets. Since then, Vernagtferner experienced a series of strongly negative mass balance years, especially in the 1990's. Results of the application of an advanced version of the model will be presented. The new version starts from measured winter snow accumulation, it calculates albedo changes caused by the ageing of the snow, and includes monoplots of photos for verification of the modelled snow-ice distribution. Modelled and observed ablation pattern and runoff values agree rather well, not only for periods with extensive melting, but also for summers with frequent snowfall events.

Extreme floods from combined snowmelt and rain events

by Aanund Killingtveit, NTNU, Norway
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In Norway some of the most extreme floods occur as a combination of snowmelt and rainfall, even during the mid-winter. The snowmelt can reach surprisingly high levels even if the air temperature is only a few degrees over 0, due to combination of strong wind and high humidity in the air. In extreme cases snowmelt over 100 mm/day seem to have occurred.

This paper will summarize the key results from several studies of snowmelt induced floods in Norway and at Svalbard, with an emphasis on combined snowmelt and rainfall events, using both degree-day and energy-balance methods to study the snowmelt.

A new research project on this topic is planned to be started in 1997, and international cooperation from other countries with similar fllod regimes is highly desired. The paper will also present the preliminary program for this project, and invite to cooperation with other research groups with similar interests.

DISTRIBUTED RADIATION BUDGET APPLIED TO MODEL SNOW MELTING AND EVAPOTRANSPIRATION IN AN ALPINE CATCHMENT

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H. Aschwanden and B. Schaedler (Swiss National Hydrological and Geological Survey, CH-3003 Bern, Switzerland)

The evapotranspiration and the snow melting are two major processes governing the hydrological cycle. Both are driven by the energy available, mainly given by the radiative net flux. In order to simulate these processes in the Landquart basin (Switzerland), surfaces with homogeneous slope, aspect and altitude have been determined on the base of a high resolution DTM and using ArcInfo. The direct solar radiation is estimated taking exposition and shading into account. The diffuse radiation in both the longwaves and in shortwaves either from the sky or from the surrounding terrains are calculated by integrating radiances over solid angles. Snow melting and evapotranspiration are simulated applying these algorithms in the IRMB hydrological model to each cover within each region. The results of the simulations using 15 years simulations are presented.

COUPLING MESOSCALE DISTRIBUTED HYDROLOGICAL AND ATMOSPHERICAL MODELS: APPLICATION TO TWO FRENCH BASINS, THE RHONE AND THE ADOUR RIVER

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Some modelling of a coupled hydrological and atmospherical mesoscale model will be presented over 2 contrasted watersheds : a flat and forested basin (the Adour river, 100x100 km2), and a large and mountainous basin (the Rhone river, 600x400 km2). The coupled system consists in a land surface scheme, embedded in a distributed hydrological model. All the atmospherical variables (temperature, wind speed, specific humidity, radiation fluxes and precipitation) are obtained every 3 hours from the network of automatic atmospheric stations. The maps of vegetation properties and of soils characteristics are computed using all the existing data bases. More than 30 gauging stations over the Adour river, and 60 over the Rhone river are available for the validation. Simulations of the various components of the annual water budget will be discussed. Some sensitivity tests on the formulation of the surface runoff, the subsurface runoff, and land surface characteristics will also be presented.

ESTIMATION OF AREAL PRECIPITATION AND TEMPERATURE FOR HYDROLOGICAL MODELLING IN NORTHERN SWEDEN

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The Swedish rivers most important to hydropower production originates in the mountainous regions towards the Norwegian boarder. The precipitation is high and both for reservoir planning and flood warning purposes, it is essential with reliable runoff forecasts, based on hydrological models. The accuracy of the runoff models depends to a large extent on the accuracy and the homogeineity of the input data. As the areas are sparsely populated and the precipitation gradients are large, the few stations available do not fully represent the catchments. To improve the estimate of areal precipitation and temperature, optimal interpolation has been tested. This method, which is common in meteorological applications, considers to a certain extent systematic variations due to, e.g., topography. Data from meteorological stations, radars and a meteorological model (HIRLAM) are combined.The results indicate that this interpolation technique is more accurate than one based purely on distances or subjective weighting. It is also less sensitive to gaps in input data series, but one can still not count on homogenous estimates if there is a major loss of data from meteorological stations. In Sweden the method is used, among other things, to determine the initial conditions for the meteorological forecasting model. This means that it is fully operational, and that the estimated values are more on a level with forecasted precipitation and temperature than estimates by other methods.

A SEMI-ANALYTICAL MODEL OF OROGRAPHIC RAINFALL ENHANCEMENT.

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It is investigated to what extent the classical concept of rainfall enhancement by orographically forced uplift explains observed mesoscale precipitation patterns in Alpine areas. Orographic rain formation is modeled in a 2 1/2-dimensional framework using a kinematic airflow model based on the dividing streamline concept and water budget equations employing Kessler-type conversion parameterizations. The field of vertical motion is calculated as a superposition of a directly forced component close to mountain top and a contribution from low-level blocking. Precipitation generated at mid- and upper-tropspheric levels by large-scale processes is prescribed as a boundary condition ('seeding') at the top of the model at about 4 km. Depending on wind-speed and inflowing moisture, enhancement of this precipitation occurs as a result of accretion in orographically generated clouds at lower levels ('seeder-feeder' effect). An operational version of the model, covering the Austrian part of the Alps with a terrain resolution of about 5 km, uses boundary conditions based on prognostic models (ECMW, ALADIN). Predicted areal distributions of 12-h rainfall amounts obtained from the model are compared to surface observations. The sensitivity of calculated areal rainfall patterns to model assumptions and parameters, as well as to inflow conditions, is evaluated.

RECHARGE AREA AND HYDRODYNAMICS OF A SPRING IN AN ALPINE DOLOMITIC KARST AQUIFER USING THE ALTITUDE EFFECTS OF SPECIFIC DISCHARGE AND ISOTOPE CONTENT

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The area of investigation is situated in the Northern Limestone Alps. It consists primarily of dolomites with fine-fractured joint networks and intensively karstified limestones with shallow karst drainage channels. The investigations were especially aimed at the recharge area of the main spring "Kaltwasserquelle" (MQ = 174 l/s), which is draining a dolomitic aquifer. The hydrological catchment model is mainly based on morphometric parameters of orographical drainage basins. The data from small catchment areas with different mean altitudes were used for the calibration showing similar computed and measured specific discharges. Deviations from the model can be quantified as deficits (recharge areas) and surplus (discharge areas). The altitude effect of the stable isotope ^{18}O was used for the estimation of the mean altitudes of the recharge areas of springs (decrease of 0.22 δ ‰/100 m). The combination of both models allows the estimation of the surface and mean altitude of the recharge area and indicates high differences between the orographic catchments and the recharge areas. The effective porosity of the dolomitic aquifer could be estimated as $p^* = 2$ %.

DISTRIBUTED GLACIER MELT MODELLING

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On Storglaciaren, a small valley glacier in Sweden (3 km^2), several automatic weather stations werde operated during the melt seasons in 1993 and 1994. Ablat ion was measured by means of some 50 ablation stakes. Glacier discharge was dete rmined at the g lacier snout. These data were used to test temperature index models of glacial m elt processes. In each case, glacier melt was calculated for every hour and each grid cell of a 30 m resolution digital terrain model using the climate data col lected on the g lacier. Initially, melt was estimated using a simple degree day method. Secondly , this approach was extended by including a radiation term as a function of clea r-sky direct radiation. Melt water and rain water were routed through the glacie r using a linea r reservoir model to obtain glacier discharge. The simple degree day model yielded good results as far as the seasonal pattern of discharge was concernd but it did not reproduce the diurnal discharge fluctua tions and the spatial distribution of melt observed very well. Including the rad iation term imp roved results considerably both with regard to the diurnal discharge variations and also to the spatial distribution of melt.

HYDROLOGICAL RESEARCH OF A MOUNTAIN CATCHMENT BY MEANS OF ENVIRONMENTAL ISOTOPES

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W. Stichler (GSF-Institut für Hydrologie, D-85764 Neuherberg, Germany)

The aim of this study was to obtain additional hydrological information in a catchment in the Carpathian mountains using environmental isotopes.
The mountainous catchment under investigation (Jalovecky Creek) is situated in the Western Tatra mountains (Slovakia) with an area of 23 km^2 and a mean altitude of about 1500 m. It was established by the Slowak Acad. of Sciences. Geological it is formed mainly by Palaeozoic crystalline rocks and granodiorites. Only a narrow stripe of Mesozoic napes with prevailing limestone and dolomite occurs along the western boundary of the catchment. The mean annual precipitation is in the order of 1500 mm, the runoff about 870 mm and the mean air temperature 3.5 °C.
Main emphasis was put on the determination of the isotopic input in the hydrological system of the basin. Sampling stations in different altitude show the expected seasonal and altitude effect. During the winter months isotope measurements in the snow cover were performed. Additional, the mean isotope composition of shallow soil water was investigated in different altitude during the summer months.
The total outflow of the catchment the Jalovecky creek was sampled for isotope measurements. Runoff separations during two snow melt periods and one storm runoff event have shown that the pre-event water is dominating in runoff events. Calculated pre-event runoff contributions were in the range of 60 to 100 % for the snow melt periods and around 90 % for the measured storm runoff event.
The interpretation of the change from input to output isotopic concentration allows to estimate the mean residence time using black box models, like the dispersion model. It resulted in a calculated mean residence time of about 31 months which corresponds to an average depths of the water reservoir of about 200 cm.

HYDROLOGY OF THE CAUCASUS MINERAL WATER REGION.

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Region of the Caucasus Mineral Water is a unique as to its geological and hydrogeological conditions part of Russian Federation. Mineral water, confined to the Jurassic and Cretaceous sediments are considered to be the main natural "pearl" of this region. This factor influenced the direction of geological and hydrogeological investigations in this region. However, at present, the problem connected with surface water quality assessment becomes the most actual to the Caucasus Mineral Water region, as it is closely connected with subsoil and mineral water. Rivers in this area are the main sources for public and recreation water consumption of large health resorts and a great number of small settlements. Most of rivers are mountainous ones with high flow velocity and unstable water regime. Groundwater flows are in river alluvial deposits manifesting themselves on the surface as springs. Flows under the river-beds and rivers are in a close and their chemical composition is similar. River water quality is, in the first place, determined by the character of the territory use, belonging to the watershed areas and by towns disposition on flood lands or river terraces. So rivers, passing through health resorts can be considered to be a natural collectors for a great number of different contaminants, inflowing at organized or disorganized waste discharge, and storm and snow melt water entrance from catchment areas.

APPLICATION OF THE CONCEPTUAL WATER BALANCE MODEL „BROOK" TO A SMALL ALPINE CATCHMENT - PROCESS ORIENTED MODEL STRUCTURE INSTEAD OF PARAMETER CALIBRATION

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Runoff generation in the Löhnersbach basin, a 16 km² Alpine catchment near the skiing resort of Saalbach, Austria, is characterized by heterogeneity in space and variability in time. In situ measurements in this catchment, however, allowed to identify processe controls on runoff which are to be accounted for in hydrological modelling. The measurements highlighted the importance of runoff processes on saturated areas for the collective runoff behaviour of the mountain catchment. Runoff simulations have been performed with the water balance model BROOK, explicitly accounting for saturated area processes. Runoff simulations give close agreement with observations even though model parameters have been preset based on topographic, vegetation, and soil information rather than calibrated.

IMPACT OF CLIMATE CHANGE ON SNOWMELT AND WINTER RUNOFF

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Prof. Dr.-Ing. O. Niekamp (Hochschule Wismar)
Dipl-Geogr. Th. Hügel (Universität der Bundeswehr)

The research programm was conducted to observe the effects of possible global climatic changes on the snowmelt runoff in the river Main in northeast Bavaria. For this purpose, runoff calculations were computed by a rainfall-runoff-model which was referred to 2 self-defined stochastic scenarios (SZ 1 and 2) and 2 physically based climatic scenarios (SZ A and D) obtained by a global climate model. All scenarios were downscaled by modifying historical measured time series of 37 years and by generating time series of 100 years. The modification of precipitation and temperature lead for SZ 1 and 2 to an increase of discharge and a decrease of the return periods of extrem flood events. SZ A and D show a complete contrary reaction. These trends are also valuable for the generated long term series of 100 years. The changes of discharge depend directly on the catchment height. For the given scenarios elevated catchments show higher frequencies of high discharge than lower catchments because melting water will be concentrated in a shorter period of time. As also standard values will change (eg. HQ_{100}) flood protection constructions are to be re-examined in this context.

ASSESSMENT OF INFILTRATION AND RUNOFF CHARACTERISTICS IN DIFFERENTLY CULTIVATED AREAS OF THE UPPER SCHESA-CATCHMENT (BÜRSERBERG, VORARLBERG, AUSTRIA)

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For charcterization and definition of different runoff producing areas in the catchment of the Schesa-river representative research plots were irrigated with help of a transportable spray irrigation installation for large plots (75 m²). Water intensities applied were 30 mm/h and 100 mm/h. On these irrigated stands characteristics of vegetation and soil physical properties were determined. In addition on grassy plots composition of stand biomass was examined. Best infiltration charcteristics showed spruce forests on dolomite-rendzina soils and loose brownearth soils of the Aroza zone. Worse charcteristics were determined for wet soils, low moors and terra fusca - rendzina soils, which were intensively influenced by cattle and horse grazing. Especially on the latter stands determination of ecological indicator values (humidity value, dispersion value) pointed to much better infiltration characteristics than received from the rain simulation experiments. Irrigation repetitions before driving of cattle to the Alpine pastures showed a runoff reduction up to 50 percent and more.
Founded on the results of the study a map of the runoff coefficients was constructed as a basis for calculation of potential runoff supply to the Schesa-river in case of heavy rainfalls.

INVESTIGATIONS ON A HIGH ALPINE CATCHMENT: THE SARENNES BASIN (FRANCE)

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Investigations on a high alpine catchment are currently under process to quantify the role of the snow cover in river flows during extreme events. The Sarennes basin (28 km², outlet 1435m) covers a wide range of elevations (up to 3300m) and a small glacier is situated in the upper basin. The CIG hydrological model is used. The meteorological and snow input are provided by the meteorological analysis system SAFRAN coupled with the snow model CROCUS. Glacier mass-balance data (Cemagref) and additional measurements were used to validate the snow cover simulation. The hydrological model will be calibrated using a 10 year period, validation will be conducted on an additional 5 year period. It is planned to analyse the simulated discharge on the overall period and compare its statistical characteristics to those of the observed one. Selected case (high precipitation/discharge) and the sensitivity to snow cover will be discussed.

MISSION - ALPINE HYDROLOGY: A PROJECT TO EXPLORE THE POTENTIAL OF REMOTE SENSING FOR SNOWMELT RUNOFF MONITORING

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The project MISSION (Multi-Image Synergistic Satellite Information for the Observation of Nature) has been initiated by the Austrian Science Ministry in order to foster the operational use of remote sensing. MISSION includes 8 sub-projects in various application fields, each of which is carried out jointly by research institutes and application partners. The sub-project "Alpine Hydrology" is aimed at modelling and forecasting runoff in high Alpine drainage basins, based on synergistic use of in situ measurements and remote sensing data. Sub-basins of the Zillertaler Ache in the Austrian Alps, where the main runoff contributions originate from snow and glacier melt, have been selected for the project. Meteorological data are obtained from automatic stations, whereas areally distributed snow cover information is derived from remote sensing data. Due to the cloud-penetration, Synthetic Aperture (SAR) data of the European ERS and of the Canadian Radarsat are particularly useful for snow cover monitoring during the melt period. Optical satellite data are used to obtain complementary information on snow albedo and on glacier properties. A progress report on the project is presented, including details on the developed remote sensing techniques and on the hydrological regime.

A ONE-YEAR RECORD FROM A WEATHER STATION ON THE TONGUE OF THE MORTERATSCHGLETSCHER, SWITZERLAND

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The micro-climate of valley glaciers has hardly been studied in a systematic way. Many glacio-meteorological experiments have been limited to the summer season. Nevertheless, for testing glacier mass-balance models, used to calculate snow and ice melt from meteorological input data, data from longer periods are needed. Such records can only be obtained from automatic weather stations (AWS).
Using an AWS on a glacier for longer periods of time has its difficulties, however. First of all, it is desired to keep the sensors at about a constant height above the glacier surface. When melt rates are large, this is not simple. Secondly, there is generally no high-voltage power available. So instruments should have very little power consumption so that they can run on a simple solar panel (with a battery).
In this contribution the performance of an AWS, especially designed for glaciers, is discussed. The station is operational on the Morteratschgletscher since 1 October 1995. It measures air temperature, snow temperature, pressure, wind speed and direction, global radiation, reflected solar radiation and height of the surface (giving snow accumulation in winter and melt of snow and ice in the melt season). Data from one "balance year" (1/10 '95 - 30/9 '96) will be presented.

MODELLING RUNOFF FROM VALLEY GLACIERS FOR GLOBAL WARMING SCENARIOS

J. Oerlemans (IMAU, Princetonplein 5, 3584 CC Utrecht, Netherlands)
Z. Zuo

Runoff from glaciers will change significantly in case of global warming. On a time scale of one or two decades, changing glacier geometry will not be important (except for the smallest glaciers). When interest is on longer time scales, changing glacier geometry has to be taken into account.
We study the possible response of two glaciers, Nigardsbreen (Norway) and Pasterze (Austria) to climate warming by using dynamic ice flow models. First these models have been calibrated with the records of historic front variations. Apart from a check on model performance, the past mass-balance history is thus taken into account. In this respect the glaciers studied differ substantially: Nigardsbreen has recently experienced mostly positive balances and the Pasterze negative balances.
We present results for constant global warming rates of 0.01, 0.02 and 0.04 K/a, with and without an additional increase of precipitation of 10% per degree warming.
Differences between the glaciers turn out to be substantial. The projected runoff curves depend on the physical characteristics of the glaciers, notably hypsometry, bed profile, and response time.

THE IMPACT OF STREAM CHANNEL GEOMETRY ON THE DISTRIBUTED MODELING OF CATCHMENT DYNAMICS

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A simple and efficient procedure for incorporating the effects of stream channel geometry in the diffusion wave modeling of distributed catchment dynamics is developed. At-a-station and downstream fluvial relationships are coupled and the obtained laws of variability in space and time for water-surface width and wetted perimeter are incorporated in a Muskingum-Cunge routing scheme with variable parameters. It is shown analytically how, in the context of a diffusion wave formulation, width-discharge and wetted perimeter-discharge fluvial relationships synthesize the information needed to describe the nonlinear effects of the shape of natural cross sections on flow propagation. The developed procedure is applied to the approximately 840-km² Sieve catchment (Central Italian Appennines) to test the possibility of estimating network parameters from channel surveys and to assess the impact of the stream channel geometry on catchment dynamics. The incorporation of the estimated network features into the routing model produces a significant improvement in the flood hydrograph description at the catchment outlet with respect to less detailed network parameterizations. In addition, the results obtained from a "downstream" analysis of velocity fields indicate that the stream characteristics related to the locally-varying cross section shape may have a profound impact on flow propagation and thus they should be monitored and synthesized for a comprehensive description of the distributed catchment dynamics.

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Energy balance measurements were performed at 4 locations in the Dischma Valley near Davos, Switzerland during Summer 1995 and 1996. The measurment sites were situated at altitudes of 1700 m to 2300 m a.s.l. over alpine meadow and bare rock at differently exposed locations within the valley. Evapotranspiration was determined at all locations using the Bowen ratio method, the Penman-Montheith approach and by flux-profile relationships. At all sites, net radiation is the only energy source and evapotranspiration is highly correlated to net radiation. Comparison between the results of the different locations shows that the evapotranspiration is regulated by the available radiative energy, by the moisture conditions of the soil and by the physiological behaviour of the vegetation. The Bowen ratio was found to be significantly lower (< 0.5) at the valley floor than at higher elevations (~ 0.8). This is mainly attributed to the larger global radiation and larger water vapour deficit at the higher elevation. The measurements were used as a validation for a regional evaporation model and a good accordance was found.

Application of the HBV model to a mountainous catchment - looking for the optimal model structure

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The HBV model, a conceptual rainfall-runoff model, was applied to the mountainous 40 km^2-Brugga catchment in the Black Forest, Germany. The aim of this study was to investigate to what extend an increased representation of spatial variability in a conceptual model can be motivated by improvements of the discharge simulations. Starting from a completely lumped representation of the catchment different versions of the model allowing for increasing spatial variability were tested. In some of the versions the traditional structure of the HBV model was modified. The total number of parameters used in the different versions was kept constant to allow comparison of the results and the only additional information was elevation and land-use data. Taking into account spatial variability gave in some cases, as, for instance, increasing the number of elevation zones, significant better simulations in terms of discharge. In other cases the goodness of discharge simulation was not increased significantly even if the physical soundness of the model was improved.

WATER-BEARING FAULTS IN TRANS-BAIKAL REGION

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All faults of Trans - Baikal region may be devided into 3 main groups: the oldest deep faults NE direction, wich are parts of diverging Mongol-Ochotsk fault zone and formed geological structuries; later regional faults NW direction formed block construction of territory and controll different deposits on intersection with first; local faults cleaving massifs and basins, controlling *redistribution of ground water* between hydrogeological structures and mine-water influx into outputs.
Our long-time experience on some deposits lets to ascertain some regularities of ground water distribution in different fractures. Water-bearing faults formed in postmineral time, stretch to N-NW and develop as strike-slip and normal faults. Biangular faulting complicated between layers fractures in basin's sedimental-volcanic cover are especially water-abundant.
This features were used in industrial calculation of water-influx into outputs on deposits and ecological estimation of pollution movement over faults.

MAPPING CLIMATOLOGICAL ELEMENTS USING GEOGRAPHICAL INFORMATION SYSTEMS (GIS).

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The spatial variability of climatological elements are strongly influenced by physiographical parameters. Temperature and precipitation are affected by elevation, slope, distance from coast etc. The influence of physiography on climatological elements have traditionally been difficult to handle in climatological analyses, due to the huge amount of information. Mapping of spatial variations in climatological elements have been done manually, a subjective and time consuming process, or it have been done using generalized methods.

By applying GIS, detailed physiographical information can be included in climatological analyses. Special benefits are achieved for mountainous areas with large terrain variations.

Preliminary studies made in Norway, where the terrain variations and climate gradients are large, show promising results using simple algorithms to establish maps of temperature and precipitation mean values. The vertical and horizontal gradients, and their relation to physiographical parameters will be studied further.

These results are important in establishing consistent water balance maps in Norway. They may also be used in downscaling large- and meso-scale model output to values at local (small) scale. Advantages obtained by using GIS in climatological mapping are objective, consistent and time efficient calculations.

Application of the HBV-model in a mountainous catchment - the problem of parameter uncertainty

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The HBV model, a conceptual rainfall-runoff model, was applied to the mountainous Brugga basin (40 km^2) in the Southern Black Forest, Germany. The basin is located in the fractured gneiss formation, has a nival runoff regime and the elevation range from 400 to 1500 m a.s.l.. Good simulations of observed stream discharge were obtained. However, it was not possible to find one unique 'best' parameter set, but different parameter sets gave similar good results during the 10-year calibration period. This may be a serious problem as different parameter sets can give very different results during periods outside the calibration period. In this study the uncertainty in model predictions arising from the uncertainty in the parameterisation has been addressed. In order to reduce the uncertainty of the parameter estimation, it was tried to combine different objective functions and to include additional information as continuously recorded electrical conductivity and other environmental tracers.

LOCALISED ENERGY BALANCE AND HYDROLOGICAL REGIMES ON A TROPICAL GLACIER.

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A detailed meteorological experiment was carried out in the vicinity of the equilibrium line (5150 m a.s.l.) on Zongo Glacier, Bolivia, 16 °S, during two hydrological years. Semi-hourly values of precise localised energy balance were calculated from measurements made by a meteorological station and direct observations on the glacier. The proglacial stream discharge is roughly 5 times higher during the wet season (November - March) than during the dry season, although the incoming energy supply at the glacier surface is a little lower during the accumulation period. Indeed, net radiation is poorly correlated to discharge, with lowest values during the rainy season due to increased cloudiness and high albedo. Also, the small annual variation of air temperature cannot explain this large seasonality of melt rates. Hence, each term of energy flux is evaluated separately to determine how its magnitude changes throughout the year. Heat transfer into the ice and heat supplied by precipitation are negligible. Hence, radiation and turbulent fluxes dominate the surface energy balance. Sensible heat flux remains small most of the time although latent heat flux is highly variable with seasons. At the dry period, vapour pressure vertical gradients are significant and thus sublimation is high whereas during the wet season, the latent heat flux is negligible. This high sublimation of the dry season typical of tropical glaciers and materialised by developing penitents, is the main reason why hydrological regimes are so variable with seasons. During the dry period, a large part of the energy supplied by radiation is used to evaporate snow and therefore, energy available for melting is low, leading to low melt rates. Whereas during the accumulation season, sublimation remains very low, energy supplied by radiation is slightly lower but is directly consumed by melting, explaining why discharge is high.

THE WATER BALANCE OF A SMALL ABANDONED MOUNTAIN CATCHMENT IN THE CENTRAL SPANISH PYRENEES

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Instrumentation of the previously cultivated Loma de Arnás catchment in the central Spanish Pyrenees started in 1994. Initially rainfall, discharge, water temperature, water nutrient content and bed sediment load transport were monitored. Since then further measurements have been initiated including a distribution of points for repeated soil mositure measurement using Time Domain Reflectometry, and measurements of water vapour flux on sunny and shady slopes using Bowen Ratio Stations. Together with information on the spatial variability of rainfall in this area and preliminary applications of a physically-based hydrological model (SHETRAN) it is possible to make interpretations of the hydrological behaviour of the catchment. This paper presents the first results of the water balance of the catchment and discusses implications for other abandoned areas in the region.

PRELIMINARY APPLICATIONS OF THE PHYSICALLY-BASED MODELLING SYSTEM SHETRAN TO SMALL CATCHMENTS IN THE SPANISH PYRENEES

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As part of the EC project VAHMPIRE the physically-based hydrological modelling system SHETRAN is being applied to a series of experimental basins in the Spanish Pyrenees. The Cal Rodó basins in the Catalan Pyrenees present a range of problems for the modeller, including areas of karst, badlands and terracing. Further to the west, in the Aragonese Pyrenees a series of three basins representing a range of mountain conditions and land uses are being monitored and modelled. These cover a range of conditions from a high mountain pasture area, to mid-mountain forested areas and abandoned agricultural land. This paper discusses the results from preliminary applications of the model and lessons that can be learnt about hydrological behavious in these different situations.

ESTIMATION OF RAINFALL AND DISCHARGE DURING THE BIESCAS CAMPSITE DISASTER

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On the evening of the 7th August 1996 a violent thunderstorm occurred over the Arás catchment near the town of Biescas in the central Spanish Pyrenees. The resultant flood destroyed a campsite situated on the alluvial fan at the catchment outlet. 87 people were killed, the main road was cut and considerable damage was done to infrastructure in the catchment and the downstream channels. No rainfall or discharge measurements were available from the Arás catchment, so a programme of field measurements were used to estimate peak flows and rainfalls. This paper details the processes used and the results obtained. The information obtained was put into a wider spatial and temporal context using data from other flood events and surrounding raingauges, and results of this work will also be presented.

HS10/OA15 The integration of meteorological model forecasts into real-time flood forecasting systems

Convener: Bruen, M.
Co-Conveners: Saelthun, N.R.; Siccardi, F.; Todini, E.

DETERMINISTIC AND STOCHASTIC PRECIPITATION FORECASTS

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The recent spread of Limited Area Models (LAM) has allowed the precipitation forecasts to be issued for time horizons of 12-24-48 hours. Unfortunately LAM deterministic precipitation forecast have not yet reached the operational quality needed for extending flood forecast in the nearby future: it is therefore necessary to correct the precipitation forecast by means of precipitation observations. It was recently developed a real-time forecasting system for the Danube where the DWD rainfall forecasts were corrected by means of a Kalman Filter based on observations provided by raingauge network and showed the improvment that could be obtained. In addition, differently from a stochastic precipitation models, LAM precipitation forecasts do not provide in general a measure of their uncertainty. A multivariate Conditional rainfall model based upon a Bayesian approach has been recently developed showing extremely interesting forecasting properties for short time horizons (< 24 hrs). The forecast ensambles generated by this thecnique will be taken as a priori estimates of future rain and will combined (in Bayesian terms) to the LAM forecast, also accounting for the bias and the variance of LAM forecasting ensamble. This ensamble will therefore results as being conditioned on recent past observations as well as on LAM forecasts, and it is believed that it will show lesser bias as well as reduced uncertainty.with respect to each of the two components.

DETERMINATION OF EFFECTIVE CATCHMENT RAINFALL BY ROOT SELECTION FOR SEVERE FLOOD EVENTS

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Two key elements in the linking of atmospheric models and hydrologic models for flood prediction are (1) the estimation of areal rainfall from point rainfall measurements for comparison with forecasts and (2) the determination of the effective rainfall which is responsible for the rapid component of the hydrological response of the catchment. Difficulties can arise in assessing the performance of both the meteorological and hydrological models separately because of the often large uncertainties involved in both steps (1) and (2).

A novel method that addresses both difficulties is the root selection approach which estimates the effective rainfall for a given storm from the measured runoff from the catchment and also gives an estimate of the unit hydrograph for the catchment. The method is being further developed and applied to verifying flood forecasting models and links between their hydrological and meteorological components as part of the European Union sponsored research project TELFLOOD (ENV4-CT96-0257) Here the method is demonstrated and tested on synthetic data examples and then applied to historical runoff data for the Dodder catchment which causes severe flooding in Dublin city.

QUANTITATIVE ESTIMATION OF PRECIPITATION OVER DRAINAGE BASINS USING A NWP-MODEL SYSTEM.

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The purpose of the TELFLOOD project is to try to estimate when flooding is likely to appear, i.e. to develop methods for forecasting on the timescale of about 12h. It means that the system shall contain both meteorological and hydrological componenets. For the meteorological part, the purpose is to give quantitatively good precipitation estimates, over relatively small drainage basins. We have made experiments with the HIRLAM model system for short range forecasting. It has been found that the precipitation forecasts are sensitive to the horizontal resolution of the model. When the resolution increases we have found that also the noise level increases, i.e. the more detailed precipitation distribution, which is obtained also create false information. Also the so called "spinup" problem has to be taken into account. We have found that NWP-models of this type can give good broad descriptions of the precipitation pattern, if the resolution is high enough (i.e. about 10-20 km), but it is very difficult to estimate the actual amount over a small drainage basin, (information from a few gridpoints). An experiment with 10 consecutive HIRLAM forecasts gave about 70% of the precipitation estimated by utilizing climate stations. Using real time information in a mesoscale analysis system, which should be some kind of upper quality limit of gridded information, has been found to be sufficient for these purposes. These experiments points at statistical interpretation of model data of reasonable resolution, perhaps combined with a monte carlo technique, to estimate the uncertanty of the current precipitation amount.

DEVELOPMENT OF A NUMERICAL MODEL TO PREVENT FLOODS IN THE WESTERN MEDITERRANEAN AREA.

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During the last two decades intensive precipitations over the Western Mediterranean Area and the Iberian Peninsula have been registered. As a consequence, these intensive downpours have caused human looses and billions of dollars in economical damages.
Nowadays, we are running an ETA model centered over the Iberian Peninsula. Using these output data, a Q-vector analysis determining the convergence areas is done. This methodology will be implemented in an Expet System in order to forecast these mesoscale convective phenomena related with the strongest floods in Spain.

COUPLING METEOROLOGICAL AD HYDROLOGICAL MODELS IN REAL TIME FLOOD FORECAS TING SYSTEMS: THE EXPERIENCE OF THE LIGURIA REGION.

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A real time flood forecasting system is strictly related to the characteristic s pace and time scales of the catchments involved. The use of real time observations of meteorological and hydrological parameters, as rainfall and discharge, allows the use of a real time flood forec asting procedures based only on hydrological modelling. The usefulness of the results for an early warni ng system is strictly related to the characteristic temporal scale of the basin response: the lead tim e between forecasting and occurrence of the flood event cannot be greater than the catchment response time. For regions characterised by tormented orography and small to medium size catchments the las t approach is not suitable to provide an early warning to the population. In this case rainfall fo recasting is necessary to increase the lead time between flood forecasting and occurrence. Many different solutions are suitable for this purpose. The approach chosen by the Liguria region is to coupl e meteorological forecasting provided by Limited Area Models, with small spatial and temporal res olution, and distributed hydrological models. The reliability of the results coming from this approach is investigated and presented here. The results show that, for basins which charact eristic spatial and temporal scales of the runoff process are of the same order of the resolution of the LAM, the lead time of the flood forecasting can be increased of about 24 hours.

INTEGRATION OF A MESOSCALE NUMERICAL MODEL INTO A SYSTEM FOR SHORT PERIOD PRECIPITATION FORECASTING

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Historically, there has existed a gulf in quality between the detailed precipitation distribution that can be derived from observational data, and the more general forecasts produced from predictions of atmospheric state. An automated system (Nimrod) for generating analyses and very short-period forecasts of precipitation has been developed at the United Kingdom Meteorological Office (UKMO) in an attempt to bridge this gap. The system combines information from radar, satellites and meteorological observing stations together with forecasts from the UKMO's mesoscale numerical weather prediction (NWP) model. Forecasts of freezing level, low level wind and relative humidity are used together with cloud top height from satellite imagery and radar reflectivities to derive improved analyses of surface precipitation. The Nimrod precipitation forecast combines simple advection forecasts with NWP model precipitation forecasts, with increased weight applied to the NWP forecasts with increased lead time. The trend in the NWP model forecast is then used to introduce an element of development into the Nimrod forecast. The analyses and forecasts of precipitation generated are used both quantitatively and qualitatively by meteorological and hydrological forecasters.

FLOOD FORECASTING IN PRACTICE

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During the spring flood of 1995 in the Glomma River Basin, South Eastern Norway, forecasting discharges and water levels was of utmost importance for the society. After the flood, the general discussion on the present flood forecasting services in Norway has focused on both the quality of the forecasts and on their distribution and interpretation. The article discuss considerations concerning the production and issuing of flood forecasts. In addition the main results of a comprehensive analysis of the influence of different error sources is reported. These include the uncertainties of meteorological forecasts, runoff-rainfall modelling, river routing and modelling of flood plains.

STATISTICAL DESCRIPTION OF RAINFALL PATTERNS FOR AN UNBIASED FLOOD FORECAST USING METEOROLOGICAL MODELS

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The feasibility of coupling quantitative precipitation forecasting, deriving from atmosphere numerical modeling, with hydrological models, in order to yield improved flood forecasts, is investigated. The sparse space-time resolution of the operational meteorological forecast leads to a biased estimate of the hydrological response, due to the high non-linearity of the runoff formation process. Using a distributed rainfall-runoff model, we analyse the improvement in the flood forecast deriving from the knowledge of some statistical parameters which, attached to the usual forecast of the rainfall expected values, allow a more correct estimate of the runoff at the event and watershed scales. For an ensemble of events (described in term of rainfall and discharge), a comparison between real and predicted runoff is made under different hyphotesis of the statistical "richness" of the meteorological forecast. In this framework, with the aim to achieve more statistical informations on the spatial rainfall patterns, some meterological indicators, which are able to predict to the convective status of the precipitation event, are tested. In particular, the obtained results show how a correct estimate of the rainfall zero-probability inside each event, being a fundamental intermittency indicator, is also crucial to the purpose of the hydrologic prediction.

A METEOROLOGICAL MODEL COUPLED WITH A HYDROLOGICAL MODEL - THE EFFECT ON SOIL WETNESS, EVAPOTRANSPIRATION, CLOUD AND PRECIPITATION FORMATION

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In meteorological models usually lateral components of changes in soil moisture are neglected. Since precipitation increases with height, neglecting lateral motions in soil water results in wet mountain tops and dry valleys. To overcome this misprediction the hydrologic precipitation-runoff model NASMO of the University of Braunschweig is driven by precipitation and evapotranspiration data provided by the Leipzig's version of non-hydrostatic meteorological model GESIMA using the explicit subgrid scheme. This scheme provides these data on a 1 x 1 km^2 resolution while the meteorological model runs with a 5 x 5 km^2 resolution. The lateral inflow/outflow data obtained by the hydrologic model are upscaled by aggregation to 1 x 1 km^2 data. Data are exchanged hourly. In the catchment in the meteorological model soil wetness decreases by evapotranspiration, ground water replenishment and lateral outflow of the grid cell, and increases by precipitation and lateral inflow.

Simulations with and without coupling, with and without the explicit subgrid scheme were performed. The results substantiate that the consideration of subgrid-scale heterogeneity by the explicit subgrid scheme appreciably affects evapotranspiration, soil wetness, cloud and precipitation formation. The inclusion of the lateral inflow/outflow in the equation to determine soil moisture yields only a slight change towards drier hills and moister valleys on a short time scale.

INTEGRATED SYSTEM OF OPERATIONAL MARITIME HYDROLOGY

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ISOMH is the supporting system used in Maritime Weather Office (Poland, Gdynia) by short-time forecast hydrological/oceanographical service. The storm surges and the flood waves on the rivers Wisla and Odra are the most dangerous hazard of Polish coast of Southern Baltic Sea including the Gulf of Gdańsk and Pomerania Bay (area of hydrological protection),and especially for agglomerations as Szczecin and Gdansk located close to river estuaries.
ISOMH consists 3 main parts.First part is the subsystem MORZE (subsystem SEA), grouped the programs to hydrological data acquisition, checking, coding, decoding, transmission and processing, including the preparation data-input to mathematical models. Second part is the integration system with meteorological system POGODA, which can yield the information (real-time and forecast) from above the sea (air pressure, wind direction and speed, waves). ISOMH automatically creates the meteorological data input to models. The third part of the system is mathematical subsystem to calculation the forecast, working on the basis of 4 mathematical models: hydrodynamical and statistical.

THE MODELING OF SEVERE PRECIPITATION EVENTS USING THE MC2

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Charles Lin (CERCA and McGill University)
Robert Benoit (Atmospheric Environment Service, Environment Canada)

Surface precipitation is a key input parameter for hydrological models. Verification of the precipitation field simulated by an atmospheric model is a first step in the development of a coupled atmospheric-hydrologic model. The purpose of this talk is to demonstrate the Mesoscale Compressible Community (MC2) model's ability to simulate severe precipitation at high resolution and its potential for aiding flash flood warnings. The MC2 is a non-hydrostatic mesoscale atmospheric model with a set of sophisticated physics parameterization schemes. A self-nesting feature allows model simulation at high resolution, using operational analyses, done at a coarser resolution, as initial conditions.
Results from two case studies will be presented. For the first case (October 14, 1995), the model resolution ranged from 50, 18, to 6 km. Observational data from the McGill Doppler radar were used to calibrate the model. A reasonable simulation of precipitation was obtained, both in terms of amplitude and time evolution. The same model was then used to simulate the precipitation during the Saguenay (Quebec) flash flood period (July 19-21, 1996). In this case, the model was run at resolutions of 35 and 10 km, with no further changes in model parameters. The results compare favourably with rain gauge measurements and satellite images.

HS11 Floods: generating mechanisms and their representation in deriving frequency distributions

01 Physical generating mechanisms of flood producing runoff

Convener: Blöschl, G.
Co-Convener: Obled, C.

GENERATING MECHANISMS OF FLOODS - IMPLICATIONS FOR FLOOD FREQUENCY

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Process controls on the flood frequency curve are investigated based on sensitivity analyses with a derived flood frequency model which combines a rainfall model (involving an intensity-duration-frequency-curve) with an event runoff model. In a first step we examine four study catchments for which the runoff models have been calibrated and for which the generating mechanisms of floods are known in some detail. In a second step we examine the implications of basin scale and process controls in a regional context, based on data from 489 catchments in Austria. Results indicate that non-linear runoff generation (reflected in increasing runoff coefficients with event size), random antecedent soil moisture (reflected in random runoff coefficients), and non-linear routing (reflected in faster runoff response with event size) all translate into steeper flood frequency curves than the linear case. Threshold processes in runoff generation may give rise to a kink in the flood frequency curve which reflects a change of processes with event scale. Within-storm time patterns appear to be of critical importance for flood frequency behaviour. The changeover from convective rainfall (short duration, high intensities) to synoptic rainfall (long duration, low intensities) is consistent with observed flood frequencies. Examination of the mapping of rainfall return periods to flood return periods reveals a complex interplay of catchment characteristics and rainfall characteristics. The most important control on this interplay is the dimensionless number t_c/δ which is the ratio of catchment response time to average storm duration.

THE CHARACTERISATION OF SPATIAL RAINFALL DISTRIBUTION IN A HUMID TROPICAL WATERSHED (S.E. NIGERIA)

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The daily rainfall distribution across a previously unmonitored, humid tropical watershed (500 km2) is measured using a network of 40 plastic raingauges and one centrally located rainfall recorder over a period of three years. This data set is analysed using Thiessen Polygon, Kriging and Principal Components Analysis techniques to define homogeneous precipitation areas and to ascertain the significant contributing areas to measured catchment outlet runoff and flooding for that monitoring period.

Constraining uncertainty in model parameterisations: the incorporation of fuzzy estimates of saturated areas into the calibration process

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Physically-based, distributed models are over-parameterised with the consequence of multiple parameterisations from many areas of the parameter space being acceptable models. In this study, model paramerisations are conditioned on discharges, and then further conditioned on predictions of saturated areas. These areas are estimated using an index of saturation potential derived from microwave radar images (Gineste and Merot, 1996) combined with the topographic index. The uncertainty associated with the catchment-wide predictions of saturated area is explicitly incorporated into the conditioning through the weighting of estimates within a fuzzy set framework. The predictive uncertainty associated with the parameterisations are then assessed using the Generalised Likelihood Uncertainty Estimation (GLUE) methodology. It is shown that the methodology can reject many previously acceptable parameterisations with the consequence of a marked reduction in predictive uncertainty.

SYNOPTIC WEATHER TYPES AND THE DERIVATION OF FLOOD FREQUENCY CURVES FOR SCOTTISH RIVERS 1954-1992

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Partial duration flood series have been derived over the period 1964-92 for 51 gauging stations across Scotland and related to Lamb daily synoptic weather types. Most floods were found to occur on days with Westerly, Cyclonic and South-Westerly weather types, depending on catchment location and orientation. Westerly weather types are dominant across most of Scotland especially the north and west. South-Westerly weather types are regionally significant in the southwest of the country, whilst Cyclonic weather types dominate parts of north and eastern Scotland. At representative sites across Scotland each event in the partial duration flood series has been coded in terms of the weather type (Westerly, South-Westerly, Cyclonic) recorded on the day of the flood. An exponential flood frequency model for each partial duration series reveals strikingly different growth curves according to the dominant synoptic weather type. At each of the representative sites much steeper growth curves are reported for Cyclonic generated floods (northern and eastern Scotland) and South-Westerly generated floods (southwest Scotland) when compared with growth curves for floods generated by less frequent weather types. On the basis of these results an unequivocal link is postulated between the flood generating mechanism (synoptic weather types) and the growth curve of the resulting flood frequency distribution.

AN EXPERIMENTAL DISTRIBUTED VERSION OF TOPKAPI: FIRST CONSIDERATIONS

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The paper deals with a new physically based parametrization of the rainfall-runoff process, TOPKAPI, applicable at the different scales, ranging from the distributed to lumped catchment scale, to the GCMs scale. The basic idea is the coupling of the kinematic approach with the introduction of the topography of the catchment. Integrating over a finite domain the kinematic model results into a non-linear reservoir model, the solution of which allows to know the volume stored at each time t, that in turn allows to estimate the saturated areas contributing to the surface runoff. When saturation is reached at a generic location a mechanism of runoff production is started; this mechanism will be described by means of a non-linear reservoir model similar to that adopted for the soil component. The first version of TOPKAPI will assume a distributed form; this means that the application of the non-linear reservoir model and the control of the saturation degree are made on each mesh, moving along the tree of the links among the meshes themselves. Neverthless the model is intended to finally assume a lumped form. In the lumped version only the total water content stored in the catchment will be the state variable governing the dynamics of the saturated contributing area for the formation of runoff as well as the control mechanism for evapotranspiration and percolation. The model will be based on the calculation of a curve, the TOTOPS index, that contains information on the topography, the topology and the soil properties.

SIMILARITY SOLUTIONS FOR OVERLAND AND STREAM FLOWS TO STUDY WATERSHED RUNOFF

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This study investigates the use of similarity profiles for analyzing surface flows-specifically those occurring on overland and stream sections. The spatial behavior of the flow depth is approximated by a sine function, so that the partial differential equations reduce to ordinary differential equations. Solutions of these reduced equations are obtained at a much smaller computational effort, with analytical solutions available in some cases. These solutions were then extended to study surface water movement over small watersheds. These watersheds can be represented as a sequence of cascading overland flow planes and streams. The performance of the similarity solutions was studied by comparing with results from other physically-based models and experimental observations. It was concluded that the similarity solutions are more robust, and almost as accurate as numerical solutions that are obtained from physically-based models. Good agreement with experimental results was found. The potential application of such solutions for surface flow modeling over watersheds will be discussed.

PROCESSES OF RUNOFF GENERATION IN AMAZONIA

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In environments such as Amazonia, there is little information on the processes of runoff generation to provide the conceptual basis to model the effects of deforestation on streamflow. Soil water studies at the 3 paired (forest and pasture) study sites of the ABRACOS project (Gash et al., 1996) provided valuable information on these processes. In Central Amazonia, on deeply weathered tertiary sediments, published data indicate that streamflow is 91% baseflow. Under forest, virtually all of the net rainfall input infiltrates deeply, except on the floodplain where, the water table is shallow, and maintained near the surface by deep drainage/recharge from beneath the plateau and slope areas, even in the dry season. Flood flows are generated as saturated overland flow from the floodplain when the water table reaches the surface during rainfall events. The contributing area may expand up the lower slopes as seeps in years of high recharge. Baseflow discharge is controlled by the transmissivity of the floodplain deposits. The role of interflow is not clear. In pasture areas, compaction leads to surface redistribution of water and runoff in larger storms. At the site in Western Amazonia, soil water and flow generation processes differed because a shallower weathered zone above granitic bedrock at 1.5 m - 5 m led to the formation of a water table in the wet season. This rose to within 1 m of the surface and remained above 2 m for 3 - 4 months. Downslope from the study site, there were seeps feeding minor "gullies". At the site in Eastern Amazonia, the weathered zone was deeper and saturated conditions were never observed within the upper 3.6 m of the profile studied.

THE ROLE OF MICRO TOPOGRAPHY IN THE GENERATION OF «PRE-EVENT WATER» STORM FLOW

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Studies using environmental tracers consistently lead to high 'pre-event' or 'subsurface' flow contributions in the storm flow hydrograph. The Haute-Mentue (Switzerland) study is no exception : subsurface flow rates in excess of 1.0 mm/h are inferred from tracer based separations. The generation mechanisms documented in the literature (e.g. transmissivity feed-back or groundwater ridge) do not offer a satisfactory explanation for these results. Calculated subsurface flows are greater than the flux across the banks of the permanent channel network would allow. Field observations and theoretical considerations suggest that, when the watertable is close to the soil surface, micro topography and changing boundary conditions (i.e. rainfall) create *local flow paths* on the hill slopes. Local source (exfiltration) areas are connected to the permanent network by surface pathways. The significance of the ratio between the vertical dimension of micro topography and that of the permeable soil layer as well as the role of incised micro topography (e.g. rills) are discussed. Links with similar studies are established. Implications for the conceptualisation and modelling of hillslope processes are also discussed.

PROBABILITY OF RARE FLOODS: INSIGHTS FROM COMPONENT PROCESSES

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Floods are resultant events of complex interactions between many meteorological and hydrological processes. It is therefore unlikely that their probability distribution functions (pdf) have simple structures, notwithstanding the fact that their bodies can be reasonably fitted by simple distribution models. Since the component processes are by definition simpler than the resulting composite process, it is reasonable to assume that their distributions are simpler as well and that their tails are better defined by observation records than the tails of the composite process of the same length. On this assumption, it can be expected that the probability of rare floods (and their pdf's tails in general) can be better estimated by employing the pdfs of their component processes in conjunction with the flood-generating mechanisms, than they can by the traditional 'frequency analysis'. Some examples of this approach are presented.

EXPERIMENTAL ANALYSIS OF DIFFERENT RUNOFF GENERATION MECHANISMS

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Our analysis of runoff generation is related to the quick runoff components representing the direct response to a storm event including surface runoff and interflow which are frequently summarized to direct runoff. They occur in mountainous regions where the topography plays an important role. The surface runoff may originate either from precipitation intensity exceeding the soil infiltration capacity (infiltration excess) or from the rainfall amount exceeding utilizable storage capacity of the soil profile. This saturation excess refers to a variable contributing area. The interaction between topographical, soil-physical and canopy characteristics, the temporal and spatial variability of precipitation field, and the dominating runoff generation process is discussed on the basis of long-term experimental investigations in mountainous catchment areas supported by mathematical modelling. A change of runoff mechanism is observed when moving from average to extreme storm events. The terrain features lose in significance to runoff formation. The shape of the runoff hydrographs is primarily governed by precipitation parameters.

IDENTIFICATION OF THE PREDOMINANT MECHANISM FOR RUNOFF GENERATION AT DIFFERENT SCALES.

SAULNIER Georges-Marie L.T.H.E. (UMR 5564 CNRS-UJF-INPG)
OBLED Charles L.T.H.E. (UMR 5564 CNRS-UJF-INPG)

In Mediterranean catchment, two types of mechanism can describe the generation of runoff: the Horton runoff and the runoff on saturated areas. Depending on the observation scale and the type of event, one of these will be the predominant mechanism. This is expressed by the combination, or the competition, between two types of variability: the spatial variability of the hydrodynamic properties of soils, and the topographic variability. For an average range of events, physically-based models, including these two non-linear sources, gave reasonably good results in terms of flood predictions. However, for very extreme events relatively poor results were obtained. Hence, the need to take account of a third non-linear factor has been identified. During field observations, other authors have noted that certain combination of spatial variability of the soil depth together with topographic variability could describe runoff generation during very extreme events. Therefore, this observed combination has been described in a physically-based modelling approach. This presentation will show which variability, or combination of variabilities, appeared to be predominant according to the size of the catchment.

INVESTIGATION INTO THE FLOOD FORMING RUNOFF PROCESSES USING SIMULATED RAINFALL

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The lack of data on extreme flood events and the spatial variability of runoff processes at the catchment scale instigated this investigation into the mechanisms of runoff generation by means of simulated rainfall on instrumented 60 m^2 hillslopes. 48 field experiments with high precipitation intensities of between 50 and 100 mm/h were performed at various Swiss locations. The great range of runoff responses and timing of runoff generation measured is described here. The variability of the observed runoff processes between plots is also discussed. Infiltration excess overland flow was often the dominant discharge forming process but in some cases subsurface flow processes were also substantial. Criteria could be determined on the basis of soil characteristics, vegetation cover etc. which provide means for the evaluation of the occurence of the various flow processes. Although the extrapolation of the results from the hillslope to the catchment scale is difficult, these insights can be applied for the evaluation of catchment responses following extreme precipitation, and provide improved means for the determination of design floods.

ESTIMATION OF THE SOIL MOISTURE CONDITIONS USING TDR METER IN THE LASICA CATCHMENT, POLAND

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Determination of a catchment's soil moisture conditions is a fundamental problem in hydrology. A question on the catchment soil moisture state is often addressed when evaluating catchment ability for runoff generation. Besides, water storage in the upper soil layers is of great importance for sustaining or restoring natural forests, wetlands or meadows ecosystems. The undertaken study has been carried out to develop a method for identifying catchment soil moisture state using Time Domain Reflectometry (TDR) field operating meter. The research has provided empirical data on soil moisture conditions in the mid-size catchment draining mixed forest, wetlands and meadows. Soil drillings and soil moisture measurements were conducted in Spring, Summer and Fall periods of 1995 and 1996. Soil profiles, volumetric water content and shallow groundwater table were detected in selected sites with contrasting soil types and land covers. Collected soil moisture data were used to determine relations between the volumetric soil moisture content and water storage in the 0-10 cm, 0-50 cm and 0-100 cm layers, both for each selected measurement site and for the entire catchment. Given these measurements, variations of the water storage in the upper layers of different sites appear to be valid. The continuing collection of data and tests are still required for furher developments. Results are important for determining available catchment water resource for ecosystems protection.

HS11 Floods: generating mechanisms and their representation in deriving frequency distributions

02 Derivation of flood frequency distributions using rainfall runoff models

Convener: O'Connell, P.E.
Co-Convener: Blazkova, S.

THE CONSTRUCTION OF SYNTHETIC IUH 'S BY MEANS OF FRACTAL SCALING LAWS

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Many attempts to construct a synthetic IUH by means of multiple regressions between the concentration time T_c or peak flow and different landscape attributes exist.These regressions are often purely empirically motivated. Our approach is an attempt to *extract the underlying laws regarding scale transformations.* The decisive difference to other methods is that the basis for our approach is the validity of an *invariance principle for fractal scale transformations.* It seems that this is a universal property of natural channel networks, at least in the scale range considered here. It is a matter of fact that the property of simple scaling corresponds in a compact manner to the morphological characteristics of a catchment and the embedded natural channel network.

DERIVATION OF A PEAK FLOW DISTRIBUTION FUNCTION USING THE DISTRIBUTION OF RAINFALL VOLUMES AND RUNOFF COEFFICIENTS, AND UNIT HYDROGRAPH RESPONSE.

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An expression for the distribution function of (scaled) peak runoff is derived combining results of frequency analysis of rainfall volumes with the traditional concepts of runoff coefficients and the unit hydrograph. Rainfall volume, scaled with respect to its duration, is assumed to follow a gamma distribution while for the runoff coefficient a beta distribution is applied. Hydrograph characteristics are considered to be deterministic variables. A closed form analytical expression is achieved when some minor simplifications are made. The approach is tested and validated against data from 17 small Swiss drainage basins, for which unit hydrographs have been derived. The rainfall response of these basins is very different both what concerns the distribution of runoff coefficients and hydrograph characteristics, which is also reflected in the behaviour of the distribution of peak flow. Four main response classes of basins are identified which can be related to the physiography of the basins.

FLOOD FREQUENCY DISTRIBUTIONS DERIVED FROM A HYBRID POINT RAINFALL MODEL AND A HORTONIAN RAINFALL-RUNOFF MODEL

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Flood frequency distributions of minesite rehabilitated plots and small catchments in central Queensland, Australia, are presented. A hybrid point rainfall generator, a product of two random processes, (Gyasi-Agyei and Willgoose, 1997) is used to generate 1000 years of rainfall data. Natural rainfall-runoff data are used to calibrate a Hortonian rainfall-runoff model. With the calibrated parameters, the generated rainfall time series are run through the rainfall-runoff model and the peak discharge for each year is determined. The 1000 peak discharges are used to derive flood frequency distribution of each catchment. The sensitivity of the flood frequency distributions to the rainfall-runoff model parameters, as well as the time scale of simulation, are examined. The results from catchments of different sizes provide insight into the scale effects on flood frequency distributions.

USE OF A SIMULATION APPROACH TO EXPLORE VARIATIONS IN FLOOD FREQUENCY CURVES

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Variations in flood frequency curves between catchments can be ascribed to variations in catchment characteristics/catchment response and/or variations in the storm rainfall regimes. To gain an understanding of the sources of these variations, a simulation approach has been adopted in which a Neyman Scott rectangular pulses (NSRP) model is used to simulate the rainfall inputs to the ARNO rainfall runoff model. The NSRP model employed incorporates two types of rainfall cell, one relating to short duration high intensity rainfall and the second to longer duration lower intensity rainfall. Realistic sets of NSRP parameters have been derived for a number of sites in the UK, giving realistic variations in the simulated rainfall intensity-duration frequency curves. The ARNO model used to convert the generated NSRP rainfall-time series employs a distribution function description of soil moisture, while a network width function is used to route generated runoff to the basin outlet. Variations in the generated flood frequency curves are explored as a function of the NSRP and ARNO model parameters, and an analysis of variance experiment is conducted to assess the relative importance of storm and catchment parameters.

FLOOD STUDIES USING SPATIAL-TEMPORAL RAINFALL SCENARIOS DOWNSCALED FROM GCM OUTPUT

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The POPSICLE project (Production Of Precipitation Scenarios for Impact assessments of CLimate change in Europe) has produced spatial-temporal rainfall fields from GCM output for use in hydrological models for climate change impact assessments. This paper describes how GCM large-scale atmospheric flow are downscaled to rainfall statistics (daily mean and proportion of dry days), which are used to parametrize a stochastic multi-site rainfall model, the Generalised Neyman-Scott Rectangular Pulses model. Long duration, fine resolution rainfall time-series for future and current climates are then used as inputs to rainfall-runoff models to produce discharge series. Applications to the Cobres basin (Portugal) and Tyne basin (UK) using the SHETRAN and NUARNO hydrological models will be presented. Validations and future impacts will be described. This work was supported by the EC Environment and Climate Programme.

TOWARDS GENERALISED FLOOD FREQUENCY ESTIMATION USING CONTINUOUS RAINFALL-RUNOFF MODELLING

R. Lamb and A. Calver (Institute of Hydrology, Wallingford, Oxon, OX10 8BB, UK)

This paper discusses an approach to flood frequency estimation using continuous simulation of catchment runoff. The aim is to generalise the procedure for use with ungauged catchments rather than to apply it only to specific, gauged sites. Generalisation has implications for the complexity of the models used; here simple, physically-interpretable models have been employed, whose parameters are to be related to known catchment characteristics. Flow series for a range of UK catchments have been modelled at an hourly time step allowing the results to be considered in the light of flood-generating processes. It is recognised that the physical interpretation of model concepts and parameters may be inappropriate beyond a certain level. The issue of model calibration is discussed, as is the question of characterising overall catchment response for flood frequency estimation, as opposed to the precise modelling of individual flood events.

ARE FRACTAL STATISTICS APPLICABLE TO FLOOD FREQUENCY FORECASTS?

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Flood frequency forecasting has a long history and has many important applications in terms flood hazard assessment and land use. Unfortunately, the records on which forecasting is based are often relatively short. In this paper the possible applicability of power-law (fractal) statistics to flood frequency forecasting is discussed. A variety of data sets are considered including both historical flood records and data on paleofloods. In utilizing historic data the decision must be made whether to use an annual flood series or a partial duration series. The annual series has the advantage that it is well defined whereas the partial duration series requires some type of arbitrary definition in order to define "independent" floods. However, we argue that the use of the annual flood series introduces an artificial "curvature" to the data set which leads to serious underestimates of the severe flood hazard. In general the partial duration series are in better agreement with fractal statistics than the annual series. The application of power-law (fractal) statistics provides much more conservative estimates of the severe flood hazard.

FLOOD FREQUENCY DISTRIBUTIONS MADE TO ORDER

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Flood frequency analysis is routinely used for estimation of design peak discharges. The standard procedure relies on extrapolation of a probability distribution fitted to a sample of observed flows, without any recourse to physical laws governing flood generation processes. This is not a scientifically sound procedure. The aim of this paper is to show that physical (i.e. deterministic) laws play a major role in shaping the probability distribution of observed peak discharges. The direct linkage between the parent distribution of rainfall intensity, physical laws of fluid motion and the derived distribution of peak discharge for the case of runoff from an impervious plane are clearly demonstrated. Next, the discussion is extended to flood probabilities on a catchment scale. Arguments are presented to support the view that flood peaks at a given site may not necessarily conform to a single probabilistic model. Because of our imperfect knowledge of all processes operating on a catchment scale during a flood, our mathematical models contain semi-empirical stochastic parameters. Thus, a sensible appraoch to study the probabilistic nature of flood flows on a modeled watershed is to employ the Monte Carlo technique. The paper presents results of Monte Carlo simulation in which a watershed runoff model was used to generate a physically based synthetic flood frequency curve. Results are compared with those obtained by standard flood frequency analysis.

MODELLING THE FLOOD RESPONSE OF LARGE CATCHMENTS

Pam Naden, Sue Crooks and Peter Broadhurst (Institute of Hydrology, Wallingford, OX10 8BB, UK)

A continuous simulation approach to the estimation of flood frequency on large catchments is described. Initial estimates were made for three large catchments (10,000 km^2) in the UK using a semi-distributed rainfall-runoff model run on a 40 km grid scale and a daily time-step. The model comprises three components: a soil water balance model incorporating explicit representation of six different land cover types, a soil drainage model, and a basin-wide routing model. The soil water balance and drainage models were calibrated on 22 small catchments representative of the soil types found within the large basins, and a method for transferring these parameter values to grid squares was devised. When aggregated via the flow routing procedure, simulated flows at the large catchment scale and the derived flood frequency curves (based on peaks-over-threshold analysis) showed good correspondence with observed data, with the exception of a few outliers. Reasons for these outliers are explored in the paper together with an assessment of the approach for estimating the flood response of large catchments.

GEOMORPHOCLIMATIC PARAMETERS AND FLOOD FREQUENCY DISTRIBUTIONS AT REGIONAL SCALE

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B. Mazzanti (Dipartimento di Ingegneria Civile, Università degli Studi di Firenze, Italy)

In the framework of an investigation about regional flood frequency distribution in Tuscany (Italy), an extendend hydrological database (more than 500 raingauges and 60 flow gauges), and especially realized geographical archives and elaboration procedures (hydrographic network, raster maps,...) have been used. Here is presented a summary study on the relevant relationships among the,geomorphoclimatic charachteristics and flood frequency distribution parameters referring to more than 2000 watersheds.

DERIVATION OF DESIGN FLOODS USING RAINFALL RUNOFF MODELS

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A method for maximum flood frequency estimation has been proposed to be applied in the ungauged basins in Poland. Selected hydrological models have been used as a tool of transformation of the design rainfalls into design floods. Wackermann, GIUH, Lutz and Dimensionless Hydrograph models versions have been applied. Models calibration was proceeded for 11 mountainous basins from the territory of Poland. Most of them were located within mountainous regions of southern Poland. Basic criterion for the selection of basins was presence of long meteorological and hydrological data series. All basins have relatively small area which does not exceed 300 sq.km. Models calibration has required an estimation of physiographic and rainfall characteristics as well as river channel parameters. The Integrated Land and Water Information System (ILWIS) was used for evaluation of selected basins characteristics from topographic and thematic maps. Transformation of the design storms into flood hydrographs has been done assuming that maximum discharge corresponds to the rainfall of the same frequency. The results obtained from rainfall runoff models have been verified by the values of flood flows approximated by probability distribution function with parameters estimated from the empirical samples of annual maximum discharges. The method can be recommended for the estimation of flood flows of the probability greater than 10%

HS12 Soil erosion and sediment transport

01 Flow and sediment transport modelling in hydrology and geomorphology using numerical methods

Convener: Lane, S.N.
Co-Conveners: Bates, P.D.

INVESTIGATION OF CONTROLS ON SECONDARY CIRCULATION IN RIVER CHANNEL CONFLUENCES USING A THREE-DIMENSIONAL NUMERICAL MODEL

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The flow structures that develop at river channel confluences have important implications for patterns of sediment movement and solute dispersal. Previous research has identified junction angle, bed discordance and velocity ratio as key controls on confluence flow structures and mixing processes. This has been illustrated using both field measurements in natural confluences and laboratory measurements of simplified confluences. Generalisation of the results obtained from these experiments is limited by the number of confluence geometries that can be examined in a reasonable amount of time. This limitation may be overcome by numerical models, in which confluence geometry is more readily varied, and data acquired more rapidly. This paper uses a three-dimensional flow model based on the Navier-Stokes equations to simulate the flow in simple confluences with different combinations of velocity ratio, junction angle and bed discordance. Comparison of these simulations allow assesment of the relative importance and interaction of these different controls. The application of the model to natural confluences is demonstrated and analysis of the results allows the role of these different controls to be identified.

THREE DIMENSIONAL SEDIMENT TRANSPORT MODELLING WITH THE CH3D COMPUTER PROGRAM

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The U.S. Army Corps of Engineers is making progress in the field of three-dimensional sediment transport modelling. This paper describes unique features, theoretical aspects, and applications of the CH3D (Curvilinear Hydrodynamics in Three Dimensions) computer model. The model solves the three-dimensional governing equations using a boundary-fitted, finite difference solution scheme. The solution techniques of the model permit short term uncoupling of the hydrodynamic and sediment operations; allowing the computations to be performed by two separate modules of the program. The sediment transport algorithm accounts for movement of sediment as either bed load or suspended load and provides a mechanism of exchange between the two modes based on local flow characteristics. Bed sediment transport can be predicted using the transport equations of Van Rijn, Ackers & White, Laursen, or Yang. The model is capable of handling multiple grain size sediment mixtures and accounts for armoring and sorting of the bed material. CH3D has been used to investigate sedimentation characteristics in reaches of the Lower Mississippi and Atchafalaya Rivers. These investigations address issues such as channel dredging and realignment, and channel evolution.

SIMULATION OF PERIODIC UPWELLING AND MIXING PROCESSES IN RIVER CHANNEL CONFLUENCES

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Mixing processes at river channel confluences have important implications for studies of pollutant dispersal, flood routing, and in-channel habitats. Previous quantitive measurements and numerical modelling have tended only to inform average conditions, whereas qualitative observation has suggested that mixing processes are periodic in both space and time. This paper uses Large Eddy Simulation, a turbulence modelling technique not often applied to open channel flow, to simulate the periodic nature of mixing processes. Application to a simple confluence of parallel channels of unequal depths shows that it is able to simulate periodic upwelling of fluid. Flow predictions from the numerical model allow the detailed evolution of the flow structures to be examined more easily than in a laboratory experiment, where it is difficult, if not impossible, to obtain simultaneous measurements of velocity throughout the flow field. This application illustrates the role of small scale turbulence features in the generation of larger scale instabilities, so explaining the origins and nature of periodic components of mixing processes. The information that is lost if turbulence models based on Reynolds averaging are used in river channel studies, emphasises the need for careful treatment of pollutant dispersal and instream ecology in numerical modelling.

Modelling hydraulic, sediment transport and slope processes, at a catchment scale, using a cellular automaton approach.

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There have been recent advances in the numerical modelling of hydraulic and sediment transport processes at a fine scale, but the ability to extrapolate these advances to a larger scale is rarely realised. Existing approaches have been based upon linked cross sections, giving a quasi 2-d view, which is able to effectively simulate sediment transport for a single river reach. A catchment represents a whole discrete dynamic system within which there are channel, floodplain and slope processes operating over a wide range of space and time scales which present modelling problems. A Cellular Automaton (CA) approach has been used to overcome some of these difficulties, in which the landscape is represented as a series of fixed size cells. At every model iteration, each cell acts only in relation to the influence of its immediate neighbours in accordance with appropriate rules. The model presented here takes approximations of existing flow and sediment transport equations, and integrates them, together with slope and floodplain approximations, within a cellular automaton framework. This method has been applied to the Catchment of Cam Gill Beck (4.2 km2) above Starbotton, upper Wharfedale, a tributary of the River Wharfe, North Yorkshire, UK. This approach provides for the first time a workable model of the whole catchment at a meso scale (1m). The effects of a catastrophic flood event, documented in 1686 are then simulated. Preliminary results show the evolution of bars, braids, terraces and alluvial fans which are similar to those observed in the field, and indicates the emergence of significantly non-linear behaviour.

EROSION PROCESSES UNDER SPRINKLER IRRIGATION AND HOW TO MINIMIZE THEM

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A wide application of, sprinkling, as one of the most advanced methods of irrigation, is justified by scarce water resources and hilly terrain in Moldova. Different natural conditions require different irrigation facilities to be used in the Republic. However, when developing new types of irrigation facilities, the designers' efforts were mainly aimed at enhancing the irrigation capacity of these systems by increasing the power and effective radius of sprinkler jet. But at the same time, a due attention was not always paid to the problem of soil fertility conservation. There was mistaken to think that in some time soil texture can be recovered. a similar concept has given rise to the manufacturing of high - intensity sprinkling system (up to 1.2 mm/min) with a flow rate of 100 l/sec. The majority of commercial sprinkler irrigation system give a "heavy rain" irrigation that result s in the degradation of soil texture, the deterioration of water - soil relation and often causes an erosion of irrigated soil. Degradation of soil is enhanced considerably when a sloppy terrain is irrigated by sprinkling. by the following reason a high risk of erosion remains on the land with a grade exceeding 2%. Firstly, the more is the grade, the less is the pre - runoff rate and the more is the danger of runoff itself. Secondly, when applying water to a sloppy terrain the soil is subject to erosion even before the runoff is formed - up because numerous soil particles start to be transported downwards the slope under the impact of sprinkler irrigation drops. Thirdly, a irrigated slope itself is a powerful accelerator of "heavy rain" or storm runoff.

NUMERICAL MODELLING OF CHANNEL CHANGES CAUSED BY RIVER TRAINING AND RESTORATION MEASURES

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River training works, performed since the last century, caused a significant influence on sediment transport. The decrease of the river bed width and bedload retention measures in the small tributaries increased the sediment transport capacity due to increased shear stresses. As a result many Alpine gravel bed rivers show an ongoing river bed degradation. One example is the Upper Drau river in Austria, where over the last 60 years the degradation reached maximum values of 1.5 m. In order to predict the future development of the channel changes a numerical sediment transport model was applied. The results show an ongoing river bed degradation process up to 2.5 meters in maximum within the next thirty years. In order to analyze the influence of the variability of the input parameters, which was investigated by sediment transport measurements, a sensitivity analyses was performed. The results demonstrated the importance of representative data for a realistic simulation. During the project a prototype river restoration measure was realized. There the channel width was increased from 40 m to 60 m in maximum over a 300 m long reach. For this restoration measure a numerical simulation was performed and an aggradation of 0.2 m was predicted. A monitoring program over four years generally confirmed the simulation, although locally deviations, caused by the development of gravel bars, were observed. The importance of socalled key cross sections for the river channel changing process was demonstrated.

THE IMPORTANCE OF SPACE / TIME RESOLUTION IN THE DEVELOPMENT OF A MORPHODYNAMIC MODEL FOR FLOODPLAIN ENVIRONMENTS.

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Continued development of numerical algorithms has enabled the construction of high resolution space / time hydraulic models which are capable of calculating, to an acceptable accuracy, dynamic hydraulics within complex fluvial environments. Allied to these developments the availability of computational processing has increased, thus allowing more complex higher space / time resolution applications to be undertaken. This paper discusses the importance of considering space / time resolution in the application of a two dimensional horizontal finite element model for the prediction of suspended sediment dynamics within a fluvial floodplain environment. This has been achieved by considering three different flood hydrographs flowing through a hypothetical domain represented by seven finite element meshes of varying spatial resolution. The results are analysed in terms of bulk flow characteristics, internal hydraulic variables as well as post event sediment deposition patterns. The investigation shows the importance of the mesh resolution in the solution of the governing equation. In fact, the average element size has a greater effect than the friction parameter on the model output. The study also shows how discrepancies in the calculated variables can be attenuated once more processes are considered.

DEVELOPMENT OF A SUPPLY-BASED CONCEPTUAL MODEL FOR SUSPENDED SEDIMENT TRANSPORT

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A conceptual suspended sediment concentration model with moderate input demands has been developed. It is linked to the hydrological model HBV, which computes continuous and spatially distributed inputs of daily rainfall intensities and runoff. Distributed information of catchment characteristics is also needed. The model is divided into an accumulation and a yield routine. Accumulation of erodable sediment is governed by daily rainfall intensities and erosivity parameters, while sediment yield and concentration are governed by daily runoff, stream parameters and available sediment. The model is run in a distributed mode with subbasins as basic units. Parameter estimation is made through calibration against observed suspended sediment concentration.

The model was tested in a 200 km^2 catchment in the tropical parts of the Bolivian Ands. Calibration was made for one year of continuous sediment data and validation was made for the following year. The results showed that the developed model has potential to simulate the suspended sediment concentration in river basins similar to the studied area. Comparison with the sediment rating curve method showed significantly better results for the sediment model.

MODELLING SEDIMENT AND TRACE METALS TRANSPORT IN AVEIRO LAGOON, PORTUGAL

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This study concerns the development and application of a sediment and trace metal transport model coupled with a bi-dimensional depth integrated hydrodynamic model in order to predict transport of a heavy metal in the Aveiro Lagoon (Northwest of Portugal).
The hydrodynamic model is tidaly forced through an open channel at the western boundary facing the Atlantic Ocean. Influence of wind forcing is also integrated through the wind stress parameterization.
The dispersion of contaminants like heavy metals is strongly dependent on the sediment characteristic, and on their dynamics as well as on the chemical properties of the water. In the present study we have only considered the influence of the salinity, even though, other chemical factors like PH play an important role in the heavy metal-sediments interaction. At any time step the relative importance of dissolved and particulate trace metal concentration is determined by a partition coefficient defined as the ratio of this two quantities.
Results of simulations show that trace metal sediment transport play an important role in the advective-diffusive transport. It also show that in order to better predict trace metals dispersion one must understand the interaction between sediment and heavy metals and therefore a better parameterization of the partition coefficient.

An integrated model for surface runoff, infiltration of water and soil erosion

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The surface runoff plays a dominant part in the erosion of soil during excessive rainfalls. In the first part of our model we are dealing with the surface runoff and the infiltration of water on any relief: In order to describe the surface runoff we use the Manning formula that comes from the canal building. It determines the velocity of water in an arbitrary canal in dependency on the slope and the water depth. We modify and enlarge this formula in a suitable way. In conjunction with the conservation of mass we obtain a differential equation that can be solved using numerical methods. To take the infiltration into account we consider the Richards equation. This equation describes the flow of water in an unsaturated or saturated soil. Therefore it represents a generalization of Darcys law. We solve this equation using numerical methods as well and determine from that the infiltration rate for the water on the relief surface. The second part of our model consists of a formulation for soil erosion that is coupled to the runoff and infiltration model.
In order to give some practical examples we water several slopes in our model and calculate the development of the surface runoff, the infiltration and the soil erosion.

DEVELOPMENT AND PRELIMINARY TESTING OF A TWO-DIMENSIONAL FLOW AND SEDIMENT TRANSPORT MODEL WITH A LATERAL SEDIMENT SORTING ALGORITHM FOR GRAVEL-BED RIVERS

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Recent research has illustrated the potential for using numerical modelling methods in the understanding of river channel dynamics, particularly in relation to the spatial distribution of velocity and shear stress. Fully dynamic models of channel change however require a coupled flow and sediment transport model that allows: (i) evolution of bed texture as sediment transport occurs (especially for gravel-bed rivers); (ii) downstream and lateral sediment routing; (iii) bank erosion and bar formation; and (iv) feedback between changes in bed texture and channel topography and flow processes.
Previous research has developed one-dimensional models of channel response to discharge and sediment supply regimes that has incorporated these processes. However, they are not able to represent lateral processes effectively, and in certain situations (e.g. zones of flow convergence, meanders etc.) such process may be critical. This paper presents the first attempt at a fully coupled model of channel change that includes a two-dimensional sediment sorting algorithm in a coupled model for flow and sediment transport. The model allows the detailed simulation of bed sedimentary structures and fractional composition of the bed, as well as channel change. Preliminary assessment of the model has focused upon uniform beds to assess the simulation of bed morphology. The second stage of assessment will extend the problem to mixed-grain beds, with different grain-size characteristics, to assess the sediment sorting algorithm. This involves much greater uncertainty due to the introduction of new empirical parameters, notably an exchange parameter and an active layer depth parameter.

INTERNAL VALIDATION OF A TWO-DIMENSIONAL HYDRAULIC MODEL OF THE MISSOURI RIVER, USA.

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The use of internal data for validating fluvial hydraulic models has generally been somewhat inadequate due to the limited availability of such data. This is now beginning to limit the development of high resolution distributed hydraulic models. Under these conditions a two-dimensional model of a sixty kilometre reach of the Missouri River in mid-West USA has been developed. With this model the unique opportunity has arisen to use two continuously recorded internal stage measurements and synchronous satellite imagery to validate the model simulations both spatially and temporally. The opportunity also arises for a degree of process validation using the satellite imagery. The model simulations reveal that a partial but promising validation has been achieved. The predicted results are however highly dependant on the topographic representation, model discretization and physical parameters used. Use of this type of data can also be made to improve calibration procedures when parameter estimation is difficult. These results illustrate the importance of such data for highlighting problem areas in the model, improving the quality of simulations and enabling further improvements to be more carefully directed.

DERIVATION OF A PHYSICALLY-BASED EROSION MODEL FOR AN UPLAND CATCHMENT

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Common physically-based approaches in modelling surface transport processes are facing difficulties in (1) estimating overland flow parameters due to the heterogeneous microtopography, (2) computing overland flows on small grid spacing, taking into account the laws of mass and energy conservation at each grid point in order to gain realistic results. The mathematical derivation of a physically-based soil erosion model for steep watersheds using averaged conservation equations considers the sediment movement over interrill areas due to two-dimensional "sheet flow" processes. The relevant conservation equations are locally averaged over an interrill section to account for interacting overland flow of sediment towards the rills. The transport in rills is understood as one-dimensional "channel flow"; the kinematic wave approximation is applied. The locally averaged transport equations for rills and interrill areas are then averaged on a large-scale gaining the expected values of the stochastic parameters. The probability of the occurrence of rills in a combined and averaged rill-interrill transport equation finally reduces the quantitative parameter estimation. This also avoids the often experienced shortage in proper field data required by common physically-based models. The space-time variation of the spatial rill density, rill geometry and other stochastic parameters is assumed as constant during storm events as their changes are presently not understood.

MODELING OF FLOW, SAND TRANSPORT, AND BED EVOLUTION IN THE COLORADO RIVER IN GRAND CANYON, ARIZONA, USA

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The closure of Glen Canyon Dam in 1963 greatly reduced the sand supply in the Colorado River in the Grand Canyon, resulting in the erosion of the once abundant sand deposits along the 400 km river corridor below the dam. Most of the sand now supplied to the river comes from two tributaries 24 and 124 km below the dam. These deposits support riparian flora and fauna and provide campsites for visitors to Grand Canyon National Park. The success of efforts to replenish these sand deposits by releasing high discharges from Glen Canyon Dam depends in part on accurate assessments of the volume of sand residing in the channel that is available for resuspension and redistribution to the channel margins by the high flows. A model has been developed to estimate deposition and erosion rates, volumes, and locations. The model calculates the vertically averaged two-dimensional velocity field, the three-dimensional suspended sand field, and the evolution of the bed in response to changing dam releases or tributary flooding. Deviations of the measured bathymetry from the gridded topography are used to determine both the local roughness and to extract skin friction from the total boundary shear stress in the sand transport calculation. In addition to tracking sand supply, the model has been used to study the complex depositional processes that are strongly affected by the extremely irregular channel topography and numerous recirculation zones. Applications of the model include analyses of the results of tributary flooding and an experimental high flow released from the dam during March-April 1996.

LINKING HILLSLOPE AND CATCHMENT HYDROLOGY MODELS TO A MODEL OF FLOODPLAIN HYDRAULICS .

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Burt T.P. (Department of Geography, University of Durham, Durham, England).

This paper describes a modelling approach which links hillslope and catchment hydrology models to the TELEMAC2D floodplain hydraulics code. The models are tested for a reach of the River Severn in Shropshire, England, where it is seen that the balance between the gauged inflows and outflows to the reach changes throughout a winter period. The water balance depends on whether the floodplain is acting as a sink for floodwater or whether a number of ungauged catchments are producing a net influx into the reach. In order to simulate the changing hydrological conditions in the reach a number of different modelling strategies are considered, involving lumped and distributed inputs into the floodplain region. First steps are taken in producing a flexible modelling approach, where the techniques employed can be tailored to specific classes of flood events.

NUMERICAL SIMULATION OF MASS DISPERSION IN NATURAL STREAMS

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Numerical simulation have become an important implement of solution of water management problems. The two-dimensional numerical dispersion model for natural streams was developed. The model can simulate the dispersion of contamination under conditions of steady flow in nonprismatic channels. The river channel is divided along the width into flow tubes with the same discharge. Each of the tubes is divided into varying length elements so that the Courant number equals one. The model includes the possibility of simulation of outflow from unsteady contaminant source at more than one location, self-purification and the influence of the "dead zones".The model was tested for some simple cases for which there exists an analytical solution. Results of these tests show that the model produces the stable, nondispersive solutions. The model was used for simulation of pollution spreading from waste water outlet located in confluence of Ondava and Ladomirka rivers.

02 Impacts of engineering structures on erosion and sediment yield in rivers and river basins

Convener: Bathurst, J.C.
Co-Conveners: Habersack, H.M.; Schöberl, F.

CHANNEL PLANFORM AND SEDIMENT DEPOSITION BY OVERBANK FLOW

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Channel planform affects the interaction of channel and overbank flows and thence the transfer of suspended sediment load to, and its deposition, on the floodplain. Channel engineering may therefore significantly alter local deposition patterns, for example through channel straightening or through returning previously straightened channels to a meandering state. Overbank deposition patterns are also of interest for the study of floodplain development and for determining the fate of contaminants adsorbed to channel sediments. However, there is a lack of quantitative data on deposition patterns. Studies have therefore been carried out with the 10-m wide Flood Channel Facility at HR Wallingford, UK, to examine the spatial pattern of deposition of suspended sediment from the main channel flow. Two experiments in a 1.6-m wide straight channel showed deposition concentrated in berms along the channel bank. Little sediment was transferred further onto the floodplain. A single experiment with a 1.6-m wide meandering channel showed a very different pattern of deposition across the entire floodplain tongue between successive meanders. Distribution profiles illustrate the variation of deposition patterns with channel planform.

THE EFFECT OF THE SVARTISEN POWER PLANT ON THE SEDIMENT LOAD IN DOWNSTREAM WATER BODIES

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When the Svartisen power plant in Northern Norway was put in operation in 1994, extensive sediment pollution was observed in the downstream fjord area. The power plant collect water from about 70 individual intakes on its East and North - South diversion tunnels. The water from the eastern - going tunnels passes through the large Storglomvatn reservoir before entering the power station intake. Five large glaciers drain directly into the reservoir, whereas 12 others supply sediments to the diversion tunnels. Sediments are also supplied from erosion of the bed of the reservoir during low drawdown levels. This paper reports the studies carried out to asess the contribution from the various sediment sources and the calculations of the amount remaining in suspension as the sediments move through the reservoir and fjord. Sediment transport monitoring stations along the east and southern diversion tunnels recorded results of 11 000 t/yr and 17 300 t/yr respectively. Varve studies of sediment cores from the bed of the reservoir gave an estimate of the contribution from glaciers around the reservoir of 103 000 tonnes/yr. Accumulation on the bed during low drawdown in 1994 was estimated to be $2.9 * 10^{6}$ t. In the fjord, 2 km from the power station, 68% of the sediment load originated from erosion of bed sediments in 1994, 22% from the glaciers around the reservoir, and 6% from the Southern diversion tunnel. The contribution from the Eastern diversion tunnels was negligible. In 1995, the contribution from bed sediments was 23%, whereas the contribution from reservoir glaciers increased to 55%. The Southern and Eastern diversions contributed 23% and 1% in that year. The reasons for these differences are discussed.

IMPACT OF AMMAN-IRBID HIGHWAY LANDSLIDES ON EROSION AND SEDIMENT YIELD IN KING TALAL DAM

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King Talal dam is considered one of the key water project in Jordan. It was built to have a 86 x106 m3 as active storage and to serve mainly irrigation purpose in Jordan valley. This dam has been recently targeted by increased volumes of sediments originating from landslides of a newly constructed Amman-Irbid highway. Landslides are in response of mistakenly excavating the highway in weak soils. The intention behind this research is to identify sites of high landslide erosion risk and quantify their contributions to sediment yield at the reservoir mouth, and to design conservation measures to minimize their contributions to yield. Erosion risk assessment of these slides was done initially as part of the total watershed assessment, where the watershed erosion hazard was classified according drainage texture, rainfall erosion index (R), and the ratio p2/P, where p is the highest mean monthly precipitation and P is the mean annual precipitation. The classification help!s in finding areas where much concern of the conservation measures should be provided for the whole watershed. A single event model, known by AGNPS (Agriculture Non-point Source Pollution Model) developed by the Minnesota Pollution Control Agency, was implemented to differentiate between the sediment yield of the landslides and of others of the watershed. Its a is a lumped sum parameters model that basically uses the Universal Soil Loss Equation. The watershed has been descretized into 832 cells, in which the parameters of the Soil Loss Equation were estimated in each cell. Initially for model validation, the model results were compared to the actual ones collected before the construction of the highway. After that, landslides contributions were incorporated and compared to the actual results too. Many ad and hoc situations were encountered through the model application, this partly due to the accuracy of the actual sediment yield data collected, knowledge of the real developments in the watershed, and !the empirical nature of the model. In spite of these difficulties, the model provided us with means to predict sediment yield for different rainfall scenarios that would be probable in future events and design conservation practices of types suitable to reduce sediment yield at the dam mouth.

POSITIVE IMPACT OF RESERVOIRS SEDIMENTATION

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The erosion, sediment transport and sedimentation have, generally negative effects for most part of the hydraulics structures, channels, river beds and other engineering facilities. In some cases, when this phenomenon is associated with the clogging process of alluvial river bed, the sedimentation can have positive impact in the decreasing of flow rate infiltrated from lakes and reservoirs. So that, this natural phenomenon can be useful in the waterproof of artificial lakes and reservoirs created by dams and barrages systems. The piezometric head measurements show that groundwater level decrease in time, due to sedimentation and clogging processes. The paper present some of laboratory experiments, in order to establish the parameters that govern clogging process: grain sizes distribution, hydraulic gradient, time, solute concentration etc., and also the criteria that need to be taken during operation period, in order to optimise it. The case study that is presented in the second part of the paper underlines the accuracy of these ideas.

THE DEVELOPMENT OF A REGIME MODEL FOR PREDICTION OF THE LONG-TERM EFFECTS OF CIVIL ENGINEERING ACTIVITIES ON ESTUARIES

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J R Spearman and M P Dearnaley, H R Wallingford, Wallingford, Oxon, UK.

The prediction of impacts of civil engineering activities on estuaries over the long term has become an increasingly important issue, due to a variety of commercial, social and environmental reasons. Estuaries are highly complex systems involving a large number of variables and processes, many of which cannot be precisely described due to a lack of adequate theory. This gives rise to problems in the formulation of detailed numerical models and as a result such models have proved to have severe limitations in the long-term prediction of engineering activities.
A functional rather than a deterministic approach is therefore proposed, with emphasis being given to the way in which bulk parameters involving sediment transport and river and tidal discharges can be related to estuary geometry.
From a correlation analysis on a range of morphological relationships, it is shown that the relationship between peak tidal discharge and estuary cross-section at peak discharge, gives the best correlation.
A hybrid model is proposed consisting of a 1 D flow model to describe the estuary hydrodynamics coupled with a morphological algorithm to model sediment movement.
A description is given of the application of the model to a tidal barrage and a training-wall scheme.

STABILITY OF A RE-OPENED BEND OF THE RIVER DANUBE

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In order to stop erosion and to raise the bed of the River Danube the project "Blochingen Sandwinkel" was developed. It is a project of the country of Baden-Württemberg and consists in a re-opened bend of the former Danube that was connected with the existing river channel. A presumption to decrease erosion is the decrease of forces acting on the bed. This was done by an increase of the overall cross-section (with the aid of the bend) and a subsequent reduction of flow and shear velocity. Natural dynamic processes are required in the new river bed that is slightly higher located as the Danube channel. Natural data were collected at 21 cross-section profiles along the 1,7 km river course with the aim at estimating the morphological changes of this project including mass movement and bed stability. To investigate mass movement, the profiles were measured directly after the completion of the project and also one and two years later. In order to study bed stability, probes of bed material were taken at eight profiles with known h/Q-relationships.
In addition to practical experiences dealing with larger restoration projects, the investigations resulted in a detailed picture of mass movements and in a first verification of existing formulas to estimate the stability of armour layers. The formulas of *Meyer-Peter and Müller (1949), Schöberl (1979, 1991, 1992), Gessler (1965)* and *Günter (1971), Parker and Klingeman (1982)* and *Chin (1985)* were used to determine river bed stability.

STREAMBANK PROTECTION WITH SOIL BIOENGINEERING WORKS

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In rivers and streams very often bank erosion jeopardises the integrity of buildings, roads or land. Therefore, some protection measures may be necessary. As an alternative to hard engineering works, such as walls and ripraps, soil bioengineering methods can be applied. Soil biongineering techniques use only plants or plants in combination with wood, stone or other auxiliary materials. For streambank protection different methods are available. However, one main problem is that currently no accurate and reliable values about the resistance of soil bioengineering works are available. Therefore, in my lecture I will try to give an overview about the values which have so far been published world wide. Furthermore, I will present our project of the soil bioengineering experimental flume in Vienna. In this flume high water with a maximum discharge of 30-50 m3/sec can be generated artificially. With this flood discharges we intend to examine the hydraulic stress on and the resistance of the vegetation and the failure point of soil biongineering constructions.

OBSERVED IMPACTS OF FLOOD ALLEVIATION SCHEMES ON U.K. RIVERS: CAUSATION AND PREDICTION

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The stability of eighteen channel engineering works on rivers in the UK was investigated using field observation and channel resurveys. All have been operational since the 1970s. In general instability was restricted to upland schemes subject to considerable sediment transport. Inappropriate channel resectioning and dredging resulted in fill activity and over-regime channels displayed a tendency to aggrade through the construction of gravel bars. Attempts to predict unstable reaches via simple stability indices, using the design flood, indicated that stream power correctly predicted channel response for 42% of the cases studied, critical shear stress analysis predicted correctly 46% of the time and the Ackers and White transport function predicted correctly 52% of the time. Analysis of the bulk annual sediment transport characteristics of some of the rivers using daily flow data revealed a more complex temporal pattern of erosion and deposition. Modifying river channels to accommodate design flood levels often fails to consider the geomorphological significance of the engineering works and as such can promote instability. This is particularly serious on upland rivers that transport significant amounts of bed-material, where the potential for geomorphological change is greatest.

THE EFFECT OF HYDROPOWER DAMS, FLOOD PROTECTION WORKS AND RIVER GRAVEL MINES ON THE STABILITY AND SEDIMENT YIELD OF GRAVEL-BED RIVERS - SOME NORWEGIAN EXAMPLES.

T.Fergus (Dep. of Geography, P.O. Box 1042, Blindern, 0316 Oslo, Norway)

Many Norwegian rivers are affected by various technical encroachments in both the headwaters and further downstream.The long-term effect of hydropower developement on channel stability has been studied in two rivers in south-west Norway - the Fortun and the Vetlefjord - using repeat cross-section surveying to determine whether channel change has occured.This is linked to discharge data and studies of sediment supply to the channel to analyse the effects of the hydropower developement.The Fortun has experienced a large amount of aggradation and a reduction in channel capacity which is attributed to the large reduction in discharge and flood peaks while sediment supply remains unaltered.The Vetlefjord has not yet experienced any change despite having it's sediment supply unaltered and flood peaks reduced.The Bøvra is protected from hydropower developement for conservation reasons but local authorities want to increase gravel mining in the river and the channel is heavily protected by flood protection works. The long-term effects of gravel mining and flood protection works on stability and sediment yield are not yet well known in this or other Norwegian rivers. A research program has been initiated by The Norwegian Water and Electricity Administration to investigate such effects using historic survey data and new aerial survey techniques. Preliminary results from this program are presented.

THE EFFECTS OF RIVER CHANNELIZATION ON FLUVIAL PROCESSES. THE CASE OF SEGURA RIVER (SE SPAIN)

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The southern part of Spain is known for hard droughts alternating with heavy rains. In order to decrease the negative effects of these situations, Segura River has been modified and regulated since several centuries ago. Recently the last 75 km.(21% of the total length) of this river has been channelized increasing in this way its drainage capacity from 200 to 400 m^3./s. This channelization has modified the fluvial geometry of the river, and then its fluvial behaviour not only in the channelized part but in the whole river, since the relationships between bankfull flow discharge (q), width (w), depth (d), and velocity (v) have changed, and so the fluvial processes (erosion and sediment yield) are different now than before the channelization. We have selected twelve transversal sections, seven in the non-channelized part and five in the channelized one, obtaining from each section its geometric characteristics, and fitting equations w(q), d(q), and v(q) in the "natural" section of the river and in the total river. We have found that in the first case the river behaviour is similar to the rivers passing through cohesive and non-eroded terrain with velocity increasing with flow discharge. When we consider the total river, it behaves like the ones passing through a non-cohesive and easily eroded soils, and the velocity decreases in the lowest part of the river increasing in this way the sedimentation processes in this part of the river.

IMPACT OF ENGINEERING WORKS ON THE MORAVA RIVER CASE STUDY

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M.Lukac, M.Misik and Z.Capekova (WRI, L.Svobodu 5, Bratislava, Slovakia).

The lowland gravel bed river Morava creates international boundary between Slovakia and Austria in the length of 70 km. The Morava river restoration project has begun (in this part of river basin) in 1995 and will be completed in 1998. The main objectives of it are as follows: 1 on the base of a large extent field research to obtain required field data (geodesy-GIS, geophysics, hydrology, hydraulics, biology, water quality, biodiversity - fauna and flora), 2 on the base of data analyses to identify present river processes, 3 create sophisticated tools (1D and 2D mathematical models and physical model) which enable the simulations of these processes under the different boundary conditions in order to estimate the impacts of engineering works. The Morava river has been trained continually from the end of the last century. Many meanders were cut off and original river length was significantly shortened. The river regime also is influenced by the run of the engineering structures which were built on the upper part of the Morava river and also on the right hand tributary - the Dyje river. These engineering works have caused changes in the sediment transport (degradation of the river bed), fall of water levels for lower discharges, limitation of the surface water interaction between the main channel and meanders, changes in the ground water and surface water interaction, change in the flood discharge travel time (from 72 to 32,5 hours). We would like to present some preliminary results that have already been reached during the project solution. These results are focused particularly on the geophysics, geodesy, flood protection, river morphology and sediment transport (suspended sediment transport and bedload transport).

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MOSTE RESERVOIR RESTORATION PRELIMINARY DESIGN AND SEDIMENT BUDGET ESTIMATION IN THE UPPER SAVA VALLEY

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The Sava River has been impounded at Moste for more than 40 years. Overall situation is deteriorating and the safety of an 60 m high arch concrete dam is the main problem. There is no bottom outlet operating permit to flush the reservoir regularly and

EFFECT AND INFLUENCE OF A SERIES OF GROUNDSELS

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M. Fujita (Department of Forestry, Faculty of Agriculture, Kyoto University, Kyoto 606-01, Japan)

A series of groundsels are to be constructed in association with embankments to control degradation of channels in alluvial fans. Groundsels are usually gravity type structures made of concrete. The height of the groundsels is about 5 meters with fish ladders being installed on them. What I wondered was, do groundsels really avoid degradation and how badly do they influence channel erosion? An actual river where a series of groundsels is planned was taken as an example. 100 year long term water discharge, and short term large anticipated flood discharge were considered from the upstream end of the reach. Sediment was not supplied from upstream because it was assumed that sediment was checked thoroughly with check dams (sabo dams) upstream. The various conditions associated with no groundsels installed, all planned groundsels installed, and some of the planned groundsels installed were checked against river-bed elevation changes through the use of a one dimensional sediment routine computer simulation. The results showed that groundsels decrease the degradation upstream, however, they cause scoring downstream of the groundsels. One of the solutions is to construct no groundsels to realize large degradation starting from the upstream end. Another way is to slowly and incrementally construct a limited number of groundsels from the upstream end of the reach after looking at the progress of degradation. In both these cases, fish ladder are not necessary and the natural environment of alluvial channels are thus preserved as much as possible.

EFFECT OF BANK STABILIZATION ON BEND SCOUR

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Bank stabilization along migrating river bends leads to deeper outer bend scour, narrower channels and sometimes sharper bends. A simplified, axisymmetrical model of water flow, sediment transport, bank erosion and bank advance is used to study two out of four identified mechanisms for these phenomena: (1) prevention of bank sediment supply and (2) channel narrowing due to retarded point-bar growth. Tests of the model show that the effects of bank stabilization are reproduced qualitatively. Model results are compared quantitatively with data from the Ohře River in Czechoslovakia and the Brahmaputra-Jamuna River in Bangladesh.

ESTIMATION SEDIMENT YIELD IN A RIVER FOR HYDROLOGICAL SIZING OF THE SEDIMENTED RESERVOIR

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I. F. Koutur and I. Zsuffa (Department of Water Resources Engineering, Technical University of Budapest, H-1521, Budapest, Hungary)

Water with high capability for solving and moving of substances has a very high ability for transporting sediment in the river. Reservoirs not only trap the incoming sediment load but reservoir sedimentation increases the flooding risks and also decreases the storage capacity. There are main causes for the probabilistic character of the predictions such as: the stochastic character of the hydrological input and stochastic linkage between the flow of water and sediment transport. So we should analyses some probability distribution functions to have the best forecasting for sedimentation in the reservoirs. Sediment-rating curves can provide fairly satisfactory results for the prediction of mean monthly or mean annual sediment rates, but may also given good results for small and homogeneous watersheds for a day-by-day estimate. For these reasons the daily discharge data and some suspended sediment discharge data for a water gauging station for about 30 years period are analyse. The homogeneity test and distribution analysis of discharge data are done. The measured suspended sediment data are divided to the seasons groups and water stage groups, and some models examine. By some statistical method the best model is chosen and the daily suspended sediment discharge is estimated. Finally the annual sediment disposal in the reservoir is estimate.

A MATHEMATICAL FRAMEWORK FOR ZERO-DIMENSIONAL PREDICTION OF RIVER RESPONSE

E. Mosselman (DELFT HYDRAULICS, P.O. Box 177, 2600 MH Delft, The Netherlands)

A mathematical framework is presented for the zero-dimensional prediction of equilibrium states to which rivers respond after an engineering intervention. It is an extension of an existing physically-based predictor and differs from existing empirical predictors in three ways. First, it interprets the empirical coefficient of the channel width predictor physically in terms of cross-sectional shape and bank erodibility. Second, it bases a relation for braiding intensity on the width-to-depth ratio in compliance with the findings from theoretical stability analyses. Third, it produces a range of possible outcomes rather than a single result to account for the multivaluedness or history dependence of river equilibrium under given conditions. The framework is demonstrated to be a generalization of other prediction methods.

A PHYSICALLY-BASED APPROACH TO OPTIMISING BARRIER STRIP SPACING IN THE ANDEAN VALLEYS OF BOLIVIA.

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In steeplands, such as those found in Bolivia, erosion often takes the form of two types of process: surface erosion by water and the mass failure of the slope. In such environments vegetated barrier strips or stone lines have been utilised to promote soil and water conservation. While closely spaced vegetated barrier strips provide an excellent means of controlling surface runoff they may increase the soil water content by promoting infiltration. This may reduce soil cohesion and increase the likelihood of a mass failure. Thus, the use of barrier strips to control erosion in such environments is a double edged sword. To date the design of soil conservation practices on steeplands has relied upon the use of empirically-derived formulae or the judicious judgement of the farmer or soil conservation officer. This has inevitably lead to spacings being selected which may have been ineffective in controlling soil erosion or promoted mass failures. To optimise the spacing of barrier strips for erosion control and the prevention of mass failure a distributed erosion model is coupled with a slope stability model. By executing the models together for a range of soils, slopes and slope lengths a nomograph detailing the minimum permissible barrier spacing for which there is little risk of slope failure is produced.

IMPACTS ON THE NATURAL SEDIMENT DYNAMICS OF THE AUSTRIAN DANUBE

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The increased need for a flood protection scheme for Vienna was the beginning of major engineering activities on the Danube at the end of the 19th century. In the reach of Vienna the meandering and wide flowing stream (average discharge ca. $2000 m^3/s$) was narrowed into a single and straight river bed. Since the fiftieth the ongoing erection of hydropower plants along the Danube diverted the Austrian section of the Danube into an almost complete chain of reservoirs. These changes in combination with similar hydro-engineering developments on the major tributaries as well as agricultural developments in the upland catchments had a significant impact on the overall sediment dynamics of the Danube and its tributaries: (1) The annual suspended sediment loads are transported in a 50% shorter period of time than before the existence of the hydropower plants. Consequently, the suspended sediment now occurs in higher concentration during floods. (2) A recent analysis of suspended sediment data as well as a large-scale approach estimating the yields for the sub-catchments of the major Alpine basins of the Danube also indicated an increasing trend for sediment yield. Different practices in land management (increased maize cultivation often onto steep hillslopes) explain the ca. 100% sediment yield increase. (3) The lack of gravel transport through the chain of reservoirs has caused an immense river bed degradation downstream the last run-of-river station, requiring further river engineering activities in the near future.

HS12 Soil erosion and sediment transport

03 Sediment and pollution management in lake and reservoir systems

Convener: Butcher, D.
Co-Conveners: Duck, R.W.; Labadz, J.C.

SUSPENDED MATTER STUDIES IN THE LAKE KENOZERO (NW RUSSIA) AND ITS TRIBUTARIES

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In July 1996 suspended matter was studied in the Lake Kenozero and in its tributaries (Arkhangelsky Region, North-Western Russia). 17 samples of total suspended matter (TSM) and 7 samples of phythoplankton from the surface layer (0-1 m) have been collected. TSM samples were obtained by filtration of water through the Nuclepore filters (the diameter is 47 mm, pore size is 0.45 (m). Filters with TSM were dried and detailed light and scanning electron microscopy has been carried out. In tributaries concentrations of TSM varied from 0.53 to 6.83 mg/l. and it consisted mainly of mineral grains. In the lake concentrations of suspended matter generally were 0.1 -0.73 mg/l. and it consisted mainly of diatoms. At a station situated in calm bay eutrophication has been registered (concentration of potenrtially harmful cyanobacteria Anabaena sp. was 14 mg/l.).

HEAVY METALS IN URBAN WATER BODIES

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Content of pollutants in water bodies are increasing as the result of domestic, industry, agriculture and traffic impacts. One of the most dangerous substances are heavy metals (HM). They are included into biotic organisms, change the physiology of cells and become toxic for the people. The content of HM in water and sediment is one of the main indicators of urban impact on water ecosystems. In 1995 -1996 the special field research has been launched on selected lakes and their watersheds located on the territory of St.Petersburg. This work includes the measurements of atmospheric deposition, hydrological and hydrochemical characteristics of watersheds, water bodies and bottom sediments. Elaboration of the mathematical model describing HM behaviour is made simultaneously with the field observations. The results of the field research and modelling lead to the following conclusions: (i) the urban impact onto the selected water systems is very significant that is realised in the high contents of HM in water and sediment compartments, (ii) HM model shows satisfactory results in the case of using legal initial data received as the result of field research. This work was supported by the Russian Fund of Basic Researches (Project N 96-05-64166).

THE ROLE OF TECHNOGENIOUS HYDROCARBONS IN SEDIMENTARY PROCESSES IN THE NORTH TIMANO-PECHORA.

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Timano-Pechora Province is the intensive exploited oil-gas Play. The geological survey, existence of pooled recoverable hydrocarbons are accompanied by the pollutions of natural environments and upper lithosphere.
The conducted investigations were directed to the identification of oil-pollution scale in different environments, including soils, rivers, lakes and marshes, the main paths of pollutants migration and their influence to the properties of sediments, the role of sedimentological factors in the oil-pollution accumulation. A different lithofacies and morfodynamical types of sediments from oil-gas-prospects, oil-extraction and surrounded areas were investigated.
The main object of pollution is tundra soils and water reservoirs closely connected with the technological areas. But migration of sediments enriched by contamination spreads to a large squares. Hydraulic modelling shows the sifnificant influence of technogenious hydrocarbons to the size structure of sediments and accordingly the character of their migration and accumulation. In this connection the problem of technogenious sedimentation and the sedimentological control of oil-pollution is considered. The prediction of local zones of pollution accumulation in lithodynamical barriers and the possible scales of pollutions is the result of investigations.

TEMPERATURE VARIATIONS IN SOME ALPINE WATER STORAGE RESERVOIRS AND THEIR POTENTIAL IMPACT ON SEDIMENT FOCUSING

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Sediment deposition in lakes and reservoirs is commonly focused into restricted parts of the basins. In late glacial and post-glacial lacustrine systems pollen analysis of core sediments coupled with 14C dating has enabled contrasting sedimentation rates to be quantified. The processes controlling the differential rates of sedimentation are defined by the lake waters, their currents, temperatures and local supplies of sediment. In temperate countries lake waters alternate between thermally stratified and homogeneous conditions in an annual cycle. In this paper thermal radiometric studies of water temperature are reported from a series of reservoirs in the Swiss Alps. They demonstrate strongly contrasting thermal characteristics of influent streams to individual reservoirs, with cold waters derived directly from glacier melt and warm waters from streams flowing over sun-heated rocks. The radiometric methods enable the observer to plot the influence of the contrasting influent streams, and to identify zones of interaction where enhanced sedimentation is predicted.

SEDIMENT MONITORING PROGRAM IN THE "DJERDAP" RESERVOIR

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The " Djerdap I " ("Iron Gates ") Dam causes a 500 km long backwater zone on the Danube river and its tributaries. The sedimentation process in the reservoir was monitored continuously since the completion of the system in 1972. Regular field investigations consist of: (a) Surveying of the Danube river and tributaries at reference cross sections, (b) Periodic sampling of deposited sediment, (c) Daily observations of water levels and suspended sediment concentrations and (d) Complete measurements of water and sediment discharge at all sediment monitoring cross sections. The field investigation's data have been processed regularly in order to obtain full information about the sedimentation phenomena. This paper will present the review of the sediment monitoring program and give some results obtained in the passed 23-years long period.

THE WATER PLANT COMMUNITIES INFLUENCE FOR THE WATER MOVEMENT AND RIVER BEDS MORPHOLOGY

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The estimation of river overgrowing for some hydraulic parameters was the object of the study. The small rivers of the upper Biebrza area (East-Northern Poland) - very interesting from the ecological point of view - were investigated. Biebrza river and its tributaries present the natural type of the rivers with intensive overgrowing. About 160 species of vascular plants are involved in this process. Six most common plant communities were stood apart. They had the specific kind of influence for water flow conditions. The changes in river beds morphology and hydraulic parameters of the flow in three years period were measured and described. The time and intensity of accumulation phenomena and the intensity of erosion being occurring with the plant communities influence were being establishing. The water velocity distribution and the flow intensity were measured or figured out in each community once a two-three weeks. The tachoids course and specific isotaches shapes and the „dead" surface areas for each community were stated. The vegetation water lifting value was approximated. The high water lifting caused by river overgrowing is the reason of the groundwater lifting and it is converged with highest water deficit in agro- and pratacenosis.

APPLIED STUDIES OF CIRCULATION AND SEDIMENT TRANSPORT IN SHALLOW LAKES USING NUMERICAL MODELS

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Road constructions with closed dams across shallow lakes in Finland often slow down the water exchange between different parts of lakes. As a result water plants spread in closed bays, algae blooms occur more frequently, deteriorating water quality. To select the most appropriate engineering solutions to improve the present situation in lakes Sylkky and Onkivesi 3D barotropic and 2D flow and sediment transport models were applied. Different schemes of road dams modifications were simulated. Results of simulations altogether with other studies provided necessary information for selecting the technical solution to improve the water exchange in both lakes.

Contaminants in the Danube River Basin sediments and Ecological Risk Assessment methodology

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HS12-03 Sediment and pollution management in the lake and reservoir systems

The evidence of potentially harmful effects of heavy metals and organic micropollutants on aquatic organisms has led to intensive efforts towards the preparation of environmental risk assessment schemes. Therefore, the research project 101/91 „Ecological risk assessment of pollution by heavy metals and organic micropollutants in Danube catchment area (ECORISK)" has been formulated and started last year (1995) in the framework of Applied Research Programme. Based on the obtained information and knowledge strategies for risk assessment of contaminants in sediments in the Danube region have been proposed at three levels as follows:

1. Initial hazard identification method
2. Generic risk assessment
3. Site specific risk assessment

TEMPORAL PATTERNS OF PARTICLE ASSOCIATED POLLUTANTS IN RIVER BOTTOM SEDIMENTS AT DIFFERENT SCALES

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Temporal dynamics of pollutant content in river sediments over the year are not well investigated. But these investigations are a necessary requirement to understand the transport of nutrients and pollutants in river systems as well as to take representative samples from sediments. In two catchments to the south of Trier, Germany, the temporal aspect of changing sediment quality in recent sediments were investigated during two and a half years. The sediments were taken in weekly intervals and concentrations of selected nutrients, heavy metals, PAHs and PCBs were determined. The results show, that sediments have a high dynamic temporal structure within the year. The dominating processes are mixing and dilution of river bottom material by flood events as well as effluents from point and nonpoint sources. If the sediments are undisturbed for several weeks, the importance of bioaccumulation of pollutants is not neligible. Although there are only a limited number of processes, their priorities may change drastically due to changes of the hydrological conditions, which in combination with the physical and chemical properties of the contaminants lead to a very complex temporal pattern of the sediment quality. River bottom sediments in mountaineous regions are a high dynamic agent of transport with fluctuations of contaminant concentrations that are in the same magnitude as could be found for dissolved solids or contaminants associated to suspended particles. For small and medium rivers in mountaineous areas no reliable recommendations for a representative sampling can be given without knowing something about the temporal patterns of these rivers.

THE ROLE OF THE RESERVOIR IN WATER DISCOLOURATION

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The role of the reservoir in ameliorating or exacerbating delivered colour has been investigated at Lower Laithe reservoir in the United Kingdom. Water colour has been monitored at three sites; at the upstream inflow of the reservoirs integral sediment trap, at the outflow of this structure as water enters the reservoir body and at the draw-off of the reservoir. Samples were also taken to determine internal colour variations both across the reservoir's surface and vertically down its profile. The results indicate that the reservoir acts as a significant buffer to incoming colour, with the quality of abstracted water dependent on the cumulative response of the reservoir to preceding inflow events. Further analysis suggests that amelioration of colour takes place in the upper layers of the reservoir through the action of sunlight during periods of thermal stratification. Using quality and flow relationships determined between sites mathematical modelling techniques have been employed to simulate reservoir behaviour from catchment inputs. This simulation has been used to evaluate management protocols developed for the sympathetic reduction of reservoir colour using indirect management methods.

IMPACTS OF PEACE RIVER IMPOUNDMENT ON FLOW AND SEDIMENT REGIMES OF THE SLAVE RIVER DELTA, NWT

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This paper examines the impact of flow regulation on the hydrological and sediment transport regimes of the Peace and Slave Rivers. Historical hydrometric and sediment data collected by the Water Survey of Canada are used to compare mean monthly discharge for pre and post-impoundment periods. After impoundment, mean monthly discharge of the Peace River declined 16% for the ice-off period but increased 40% during ice-on periods. This has resulted in an annual post impoundment reduction of 372,491 t yr^{-1} for the Slave River. The seasonal shift in the hydrograph has changed the sediment transport dynamics of the Slave River for ice-on and ice-off periods. Sediment loads of the Slave river have increased 315% during ice-on flow but decreased 46% for ice-off flow. A reduction in flow during ice-off periods may alter the textural composition of sediment in the Slave River and subsequently reduce progradation rates of the Slave River Delta into the Great Slave Lake.

HYDRODYNAMIC MULTI-LAYER MODELING FOR POLLUTION MANAGEMENT IN RESERVOIR SYSTEMS

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This paper describes a numerical multi-layer model, developed in dimensionless form, to compute the three-dimensional water circulation and temperature structure in lakes and reservoirs. The model is based on the hydrostatic and the Boussinesq approximations and employs a quadratic relationship between density and temperature anomalies. The equations for the layered system are derived by vertical integration over layers and by defining new vertical velocities relative to the interfaces. Thereby the model allows for rigid horizontal levels, sloping permeable interfaces, moving material interfaces. The formulation of the finite differencing scheme is based on considerations of the energy balance of the physical system and on the accuracy and economy of numerical computations. Moreover the model in the case of Camastra reservoir (Southern Italy) is applied and validated, comparing the numerical results with measurement data, in order to explain the observed anoxic phenomena.

HEAVY METALS IN SURFACE SEDIMENTS OF THE LAKE LADOGA

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Sediments are considered as effective sinks for heavy metals supplied to aquatic systems in great excess from anthropogenic sources. From a study of the surface sediments one can obtains a good picture of present situation of contamination in connection with aquatic pollution control. Sediment samples from more than 200 stations in the Lake Ladoga - very important natural resource, were analysed for the next toxic metals Co, Cr, Cu, Pb, Sn, V, and Zn. The samples represent the three uppermost centimetres and approximately the 25 - 50 years at each site. The results show clearly that industrial discharges, sewage influents, and urban runoff draining to the basin directly and via inflows cause elevated heavy metals levels in the sediments. Especialy the rivers of the south part of Ladoga (Volhov, Svir, and Siays) contribute considerably to the total emission of the metals of the basin. The data on "total" contamination were normalalized to respect to the average metal concentrations in the each functional bottom type of the sediments (erosion, transportation accumulation) with the aim of the finding procedure applicable for an assessment of the sources of pollution. The application of the dispersion mapping has allowed not only to reveal the main areas of heavy metals accumulation (where the sediments are most sensitive to contamination), but also to trace directly the tracks of metals transportation from the sources of receipt up to the places of final deposition.

RESERVOIRS AS SOURCES IN SEDIMENT MANAGEMENT

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Reservoirs are long-term sinks of sediments and associated pollutants originating from municipal and industrial waste water discharge in urbanized areas and application of chemicols in agricultural land use. Trapping and mobilization of reservoir sediments are subject to the hydrological regime of the catchment, reservoir function and operation as well as sediment properties. Sediment management strategies are aiming at sediment volume minimization, sediment quality monitoring and contaminant remobilization preventing. Structural and operational options for sedimentation mitigation are presented and their specific potential impact to the aquatic environment discussed. Besides dredging, sediment sluicing and flushing is a very effective technique for sediment removal however, it normally causes a tremendous increase of suspended sediment load associated with release of dissolved and particulate pollutants. Therefore, sediment management has to monitor the in-situ sediment contaminant inventory including pore water and quantify sediment erodibility for suspended load and pollutant remobilization risk assessment. Numerical transport models are used for designing flushing measures and predicting polluted sediment mobility.

04 Extreme events: their role in sediment supply and transport

Convener: White, S.M.
Co-Convener: Summer, W.

EROSION AND SEDIMENT TRANSPORT DURING MAJOR FLOODS

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The effect of large magnitude floods on the sediment yield in rivers in Norway is discussed in this paper. In june 1995 a flood, the largest one in 200 years, occurred in South Central Norway, due to heavy rain combined with snowmelt in the mountains. The sediment load in the main stem of river Glomma was recorded to 720 000 tonnes during the flood. The annual transport during a normal year is 212 000 tonnes at the same location. The reasons for the high loads are discussed. Erosion rates of mountain rivers are normally low. It is however observed that the major floods open up a number of new sediment sources. They cause channel changes, trigger debris flows and landslides and undercut river banks. In the river Elvegårdselv a mean sediment yield of 18 tonnes/km^2 yr increased to 2034 tonnes/km^2 yr during a large flood in 1993. Channel changes, large scars in the vegetation and the lowering of river tresholds causes the new sediment sources to remain active for some time. Thus, it is suggested that the major floods may be followed by periods of higher sediment yields than normal. Their effect will vary with terrain and sediment availability.

GEOMORPHOLOGICAL INDICATORS OF EXTREME EVENTS IN THE CENTRAL SPANISH PYRENEES

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Usually studies on the recurrence of pluviometric and hydrological events are supported by statistical analysis of short data time series. In most of these series there are no records of very long return period events. However, there are several geomorphological indicators which yield information on the importance and consequences of torrential rainstorms and large floods, and even in a few cases, their recurrence intervals. The sediments deposited in alluvial fans and plains as well as the features of affected hillslopes contain much information on high intensity, low frequency events. In the case of alluvial fans, the study of sediments in the apex sector confirms the existence of long periods of minor events interrupted by accumulations of sediments belonging to very infrequent events. Recurrences of the same type of event can also be observed in large debris flows that fill entire valleys.

EXTREM FLOODS IN THE WESTERN PYRENEES

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Extrem floods are induced by heavy rainfalls with high intensity (150-250 mm per 2-5 hrs) with return periods >100 yrs. The geomorphic and anthropic factors are closely linked. We present three extrem events. In the first two, large debris flows are the major sediments transporting mechanism induced by shallow mass-movements and channels erosion. The high degradation of the wood-cover is the main factor of slopes instability. For the 1897 flood on the Bastan river (S=105 km²), we estimate a maximal discharge of 525 m^3/s and a sediment volume of 1 500 000 m^3. For the 1913 flood on the Urizate river (S=55 km²), we find similar results. Finally, the 1996 catastrophic flood of Biescas which occured in a reafforested catchment (S=18,7km²) heavily equiped with dams and ridges. About 200 mm/2h have triggered a liquid discharge of 200 m^3/s and successive dam-breaks produced a grain flow of 100 000 m^3 on the alluvial fan.

INFLUENCE OF RAINFALL AND SLOPE ANGLE ON SOIL EROSION CHARACTERISTICS IN SOUTHEASTERN NIGERIA

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Expanding the frontiers of hectarage under cultivation as a means of increasing food production has been the goal of farmers in Southeastern Nigeria after the Biafrian war of 1967 - 1970. Limited arable land and high rural population density are factors compelling farmers to extend agricutural activities onto steep marginal lands. The consequences of this in an area of high rainfall regime coupled with lack of adequate facilities for application of conservation measures were investigated. Polynomial equations accurately fitted the experimental values between soil loss and the degree of slope (R^2 = .89) and soil loss and rainfall characteristics. Eroded material was highly aggregated. Aggregation was influenced by the pattern of rainfall as well as by the intensity. Short duration high intensity impulses led to greater sediment aggregation than the low intensity long duration storms. The percentage of coarse material transported in runoff increased as the percentage of slope increased. At low slopes, reduced runoff velocity and decreased transport capacity of the overland flow caused greater particle deposition enabling more disintegration by the impacting raindrop. The dispersed eroded sediment size distribution indicated fine particle enrichment in comparison with the matrix soil. The larger the sizes of aggregates detached, the larger the percentage of the silt and clay contents mostly for soil high in these fractions in the original matrix. These effects are important and has serious implications from the standpoint of soil matrix structure, applied manure, chemical fertilizers, nutrients erosion and the water quality characteristics of the receiving streams.

A LANDSLIDE IN THE SURMA KHOLA VALLEY / HIGH MOUNTAIN REGION OF THE CENTRAL HIMALAYA IN NEPAL

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The Surma Khola catchment is situated between 2200-3410 m a.s.l. in an unsettled area with a quasi-natural *Abies-Rhododendron arboreum - Rhododendron barbatum* forest.
The High Mountain Region of the Central Nepalese Himalaya is well known for its active geomorphodynamic processes caused by the Himalayan uplift, the steepness of the slopes and the enormous precipitation amounts during the monsoon time.
In the early hours of the morning of August 10th 1990, a land slide triggered by a light earthquake occurred over a width of 35 m on the western ridge of the Surma Khola Valley. For days great amounts of water had infiltrated into the slope from a leaking irrigation channel. Within minutes, 9000 m^3 of material slipped and tumbled, dragging along the rhododendron-fir-forest and buried old slide material from earlier landslides 120 m further down. During the following 3 days, the suspended sediment concentration in the Surma Khola increased from 0.1 gl^{-1} measured before to a maximum of 8.1 gl^{-1}. The calculated sediment transport increased from 66 gs^{-1} to approx. 23 kgs^{-1}. During these 3 days, the specific suspension delivery reached 3 day 4 tha^{-1}, twice the annual suspension delivery.

SMALL MEDITERRANEAN WATERSHEDS: THE ROLE OF EXTREME EVENTS IN ORGANIC MATTER TRANSPORT AND THE RISK OF SOIL EROSION

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Extreme events are major sediment supplying and transporting mechanisms. Annual extremes of a small watershed of the Ligurian Apennines were identified and analysed over a period of 17 years, from 1953 to 1972. The capability of sediment transport for each event, and the total sediment yield for the whole research period were worked out. The respective importance of the suspended load

and of the bedload transport was evaluated. The amount of organic matter which might be carried in suspension along with the mineral fraction of the sediment w as found to be of the same order of magnitude as the average leaflitter produced ov er the study period: the average organic matter produced yearly by vegetated areas is balanced by the annual average abduction by extreme rainfall events over a few decades. This fact explains why the loss of wooded areas because of unwise management or natural accidents (clearcutting, fires, acid rains, diseases, etc.) could lead not only to the reduction of primary productivity and leaflitter production, but could also make erosion more active on the hillslopes. Possible sequences of extreme events would likely result in a dramatic loss of organic ma tter from the soil and would make the risk of denudation real.

ASSESSING SEDIMENT SOURCES USING MINERALOGICAL CHARACTERISTICS OF RESERVOIR DEPOSITS

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Identification of sediment sources at a basin scale is one of the most important problems for land management in the so-called 'marginal areas'. Sediment sources show great spatial variation according to the intensity and duration of rainstorms and the lithology and geological factors of the basin. Thus, during short, low-intensity precipitation sediment sources are restricted to the channels and nearby taluses, whilst during exceptional events the whole basin may contribute to sediment load. In large basins, with high lithological diversity, the types of transported sediments can vary greatly from one event to another. This variability remains recorded in the mineralogical composition of sediments accumulated in lakes and reservoirs. Using mineralogical and sedimentological techniques, both the most frequent sediment sources and those associated to extreme events can be identified. In this paper the results obtained in the Barasona reservoir (Esera river, central Spanish Pyrenees) are presented.

HS13 Weather radar in urban hydrology

Convener: Andrieu, H.
Co-Convener: Tilford, K.

SEDIMENT TRANSPORT DURING THE BIESCAS FLOOD

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During the Biescas flood of August 1996, large volumes of sediment were mobilised in the final stretch of the Arás river, increasing the magnitude of the disaster. At the beginning of the 20th Century and between 1940 and 1950, a number of control works had been constructed in the channel in order to reduce sediment transport towards the alluvial fan. By about 1950, the 22 existing check-dams had been completely filled with sediments and on the most active part of the alluvial fan a rapid recolonization of plants began. The flood of 7th August 1996 caused the failure of 19 of the check-dams, the cutting of a new channel in the moraine deposits alongside one of the check-dams and the mobilisation of large blocks. Sediments were deposited as boulder fans and as high density flows. The total volume of sediments moved has been estimated at 68,000 m^3, most of which were transported out of the catchment very rapidly - probably in 5 to 10 minutes.

THE IMPACT OF CHANGES IN THE FREQUENCY OF WINTER CYCLONES ON CATCHMENT SEDIMENT YIELDS

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Lake-sediment based estimates of sediment yield have frequently been used to reconstruct changing patterns of sediment supply arising from environmental change. Such analyses have often emphasised the importance of anthropogenic factors, and in particular, changing land use or management practises over timescales beyond the scope of direct process monitoring. This paper examines several UK sediment yield chronologies within the context of mescoscale atmospheric circulation patterns. Changes in the frequency of the winter cyclonic Lamb Weather Type since 1861 were found to account for a significant proportion of the variation in both contemporary and reconstructed sediment yields. This is because cyclonic weather is characterised by a high probability and volume of rainfall which in turn favours sediment detachment, rilling and surface runoff. Such results have implications for future rates of sediment yield given the potential geomorphological consequences of global climate change. Airflow indices also provide a means of downscaling extreme events from climate simulation models for catchment-scale sediment supply and transport assessments.

VARIABILITY OF RAINFIELDS AT HIGH SPACE/TIME RESOLUTION

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Abstract

A mobile weather radar was used to observe rainfall at 100 m / 6 second resolution at several locations in New Zealand. The variability of the rainfall at different spatial scales was analysed within the framework of breakdown coefficients defined as the ratio of the mean areal rainfall averaged over two different scales. The dependence of the probability distribution function of the breakdown coefficients on spatial scale was analysed. It was found that the variance of the breakdown coefficients decreases as the spatial scale is reduced, leading to the conclusion that it is possible that the variability of the rainfield does not increase without bound at the smaller scales. However the experimental verification of this is fraught with difficulties due to the difficulties in measuring rainfall at the very small scale.

A GRID BASED FLOOD FORECASTING MODEL BY USING WEATHER RADAR

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A grid based rainfall-runoff model capable of real time flood forecasting utilising highly spatial and time resolution weather radar data was developed. The model was applied to a Pinios river subbasin, the Pyli basin with a drainage area of 135 km^2. The entire basin located under the WSR-74 S-band 100 km radar umbrella was divided to 2x2 km^2 grid squares. A series of storm events recorded every 10 to 30 minutes producing flash floods were analysed and processed. The transformation of the excess rainfall to runoff discharge was performed through a transfer function. The updating of the parameters was performed in real time, every time step minimising an objective function. This objective function is the summation of the square differences between the observed and computed discharge values for a number of time steps before the time of forecast. The autoregressive model AR was implied for the simulation of the error resulting from the difference between the observed and computed values from the time of the first rise of the hydrograph until the time of forecast. Forecasting results evaluated by means of a series of statistical terms were found to be of good accuracy.

ON THE ACCURACY OF RAINFALL MEASUREMENTS USING VERY HIGH RESOLUTION RADAR DATA

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The management of both manmade and natural drainage systems involves the acquisition and use of measurements of rainfall with very high spatial and temporal resolution. Weather radars are capable of estimating rainfall with resolutions of a hundred meters or so and less than one minute. Work over many years suggests that natural variability will result in an error in point surface rainfall estimates from radar of around 35% when the bright brand is not evident in the radar beam. In this paper we revisit work carried out in the Dee Weather Radar project to demonstrate that the additional error introduced by sampling at 2 minute intervals as opposed to a 1 minute interval or less is small but evident, although the error increases quite rapidly for longer sampling intervals. Spatial sampling is somewhat more problematic. Published results indicate that reducing the spatial resolution to 1 km is only likely to give additional benefit if allowance is made for the drift of the rainfall between the radar beam and the ground. Further increase in resolution is unlikely to result in any additional increase in accuracy. On balance, it is concluded that the use of 1 km, 1 minute resolutions are appropriate for urban real-time control applications.

HYDROLOGICAL SIMULATION USING RADAR DATA IN A SMALL CATCHMENT

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Hydrologists are reluctant to use radar data for their simulations. Main reasons are traditional ways of thinking, traditional technical rules, and lacking means for checking the validity of radar measurements. The Erft River water authority is responsible for controlling the water quantity and quality in urban and rural areas of the Erft river and its tributaries. Due to very small scale flooding effects, the density of the existing raingauge network is not sufficient. Therefore, the water authority was interested in the possible gain of information by using radar data.For a small catchment of 17 km2 in the upper Norf river area the relevance of spatial rainfall variation for flooding in an urban area had to be investigated. Two approaches were compared: the use of the traditional method based on two continuously measuring raingauges and the use of radar data provided by the German Weather Service. For the investigation, the six most important flow events were selected from the period July 1995 to May 1996 including a storm with a ten year return period. Radar data were adjusted by using four raingauges in the vicinity. The NASIM simulation model was used as calibrated for the raingauge data. The analysis of the data showed that quantitative use of the provided radar data requires extreme care in data checking. Different measurement errors could be identified. A comparison of several rainrate estimation techniques was performed. A gain in spatial information by using radar data and valuable recommendations for practical use of radar data could be achieved. However, the quality of the measurement data had to be controlled and the data corrected manually.

MARSEILLE 92-93 : HYDROMETEOROLOGICAL EXPERIMENT CONSISTENCY TEST OF VARIOUS RAIN SENSORS

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The case of Marseille is typical of the Mediterranean cities prone to potentially severe hydrological hazard. The urbanisation and the marked relief surrounding the city, certainly increase the consequences of the scarce but very intense rain events. The Marseille Hydrometeorological Experiment gathers the "Service Assainissement de la ville de Marseille" and the LTHE with the aim of improving rainfall measurement and prediction techniques. The existing rainfall monitoring system is composed of a high resolution raingauge network and one of the S-band (10 cm) weather radars belonging to the french ARAMIS network located in Nîmes at 80 km from the area of interest. It was complemented with a light configuration X-band weather radar (3.2 cm) set up in the proximity of the city and a disdrometer for the characterisation of the rain drop size distributions.
A correction scheme, based on the use of mountain returns (Surface Reference Technique) was developped for correcting X-band radar data (calibration, rain attenuation) independently of raingauge measurements. Raingauge measurements were used to compute a mean assessment factor for the S-band radar data. A comparison of X and S-band estimates for the 09/23/93 rain event is proposed for various space and time scales by reference to raingauge measurements. The X-band system gives significantly better results compared to the S-band when high space and time scales are considered. Space and time integration has great potential to improve consistency between both radar and raingauge measurements. Sensitivity of results to the parametrisation of the rain drop size distribution is tested.

EVALUATION OF A SIMPLIFIED DYNAMICAL RAINFALL FORECASTING MODEL FROM RAIN EVENTS SIMULATED USING A METEOROLOGICAL MODEL

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This communication presents an evaluation of a simplified dynamical model from simulated rain events. This model is based on conservation of the rainwater content of an atmospheric column and uses multi-scan radar data and surface meteorological observations. A test of the model using radar data of Oklahoma City (USA) and Cevennes region (France) has not clearly shown the model efficiency compared to the simple extrapolation of radar observations. The proposed evaluation is based on a mono-dimensional meteorological model which serves for simulating reference rainfall. The outputs of the meteorological model: rainwater content, cloud top temperature, surface temperature, pressure and dew point are used for initialising the simplified dynamical model. The evaluation of the simplified dynamical model is performed by comparing forecasts of the model to reference rainrates. This comparison shows that the simplified dynamical model performs better than the simple extrapolation method for short lead-times up to 30 min. For longer lead-times, the dynamics of the simplified model tends to a steady state characterised by a constant rainfall rate equal to the rainfall rate forecasted using the simple extrapolation method.

REAL TIME PROCESS OF WEATHER RADAR DATA FOR URBAN HYDROLOGY : EXAMPLE OF NANCY

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Since 1994, a real time process of weather radar data has been developed in Nancy. This evolutionary system is operational and radar data are used to improve the management of the sewage system of the agglomeration.

The first part of this paper presents processing realized in real time directly by the computer receiving radar data every 5 minutes. This processing includes control of radar measurement by rain gage data, identification of rain displacements, and production of alarm signals.

The second part presents the way used to integrate radar data into the system of Centralised Technical Management (CTM) of the sewage system. Radar images and processing results are available by the same tools as other hydrological data, and alarms modify the display on the CTM monitors. This information is principally used in real time by the supervisor of the CTM to monitor and to forecast rainfall evolution. The most interesting images are recorded in a data bank to realise studies.

THE UTILISATION OF WEATHER RADARS FOR STRATEGIC URBAN DRAINAGE MODELLING

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Real Time Control strategies for large urban drainage systems are becoming increasingly important as the role of urban areas in river and coastal pollution becomes more apparent and the consequent legislation demands a more active approach to the mitigation of these problems. Weather radars can provide rainfall data at the spatial and temporal resolutions required for the modelling of large strategic pipe networks which must be undertaken if predictive active control strategies are to be implemented. They can also provide a means of extending flow forecast lead times through local quantitative precipitation forecasting (QPF) which enables the assessment of the future threat to a target catchment from a given rainfall field. This paper highlights the key issue of the scale at which the hydrometeorological processes should be considered and the consequent resolution of rainfall data required. It then details the application of QPF procedures and urban drainage modelling techniques on strategic catchments within th Manchester conurbation. Such an approach has been shown to provide the necessary interface between rainfall forecasting and hydraulic modelling tools for use in operational control of strategic urban drainage systems.

EFFICIENT ESTIMATION OF RAIN CELL KINETICS VIA HYPERGRAPH MATCHING

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This paper deals with the problem of estimating the rain cells time-space kinematics, from images obtained by weather radars.
The method proposed is based on the decomposition of a rainfall forecast into a hierarchical structure using ellipses, each level corresponding to a reflectivity threshold. At each level an ellipse models a connected component, and the rain cells kinematics are obtained by matching sets of ellipses from successive images, yielding an hypergraph decomposition. Due to rain cells chaotic behaviour (merging, splitting, births and deaths), finding a relevant matching is a difficult problem from a combinatorial point of view. To overcome this difficulty, we have developed a stochastic optimisation technique based on the simulated annealing algorithm. A change of configuration consists here in moving an ellipse from a set of ellipses to another, while penalties are added to discourage inconsistent matching. Introducing the history of past events into the cost function helps to refine the current solution.
This algorithm appears to be particularly efficient as far as small cells are concerned. Computational comparisons tend to show that our method succeeds in estimating even large displacements of cells, where classical optical flow computations fail.

EXPERIENCE OF THE APPLICATION OF 2-CHANNEL (X and S-BAND) WEATHER RADAR NETWORK FOR CLOUD AND RAINFALL MONITORING IN MOSCOW REGION

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The automatic radar system AKSOPRI is the complex for collection and processing of radar meteorological information about clouds and precipitation (rain and snow-fall). AKSOPRI operates on the basis of two channel (X-band, 9.60 GHz and S-band, 2.95 GHz) weather radar MRL-5, which is controled by IBM compatible computer. This system was designed by Russian industry under the supervision of Central Aerological Observatory (Moscow) for weather monitoring required for aviation, transport and agriculture. The range for the radar observation for one AKSOPRI is 200 km. The repetition cycle of observation is 10 minutes. The control system of AKSOPRI performs series of conical scans with various elevation angles. Specialized software builds reflectivity maps for different heights (from 500 m to 16 km), rain intensity map, storm warning map and echo tops map with 2x2 km resolution and evaluates echo movement vector. The system AKSOPRI operates in the network of weather radar. The network software builds regional radar maps and transmit mozaic information via telephone lines to users in Moscow and Moscow region. The system performs dual-wavelength observation to use the advantages of both two bands (X-band - narrow beam and high meteorological potential and S-band - practical lack of attenuation in severe storms and intensive precipitation)
In the paper we discuss a method for evaluation of X-band attenuation using dual wave-length observation. The method for correction of microwave attenuation in precipitation on the base of regularizating algorithm of solution of inverse problem of wave propogation is worked out. The results of the comparison corrected radar data with rain-gauge network data are presented.

POLARIMETRIC RADAR AT ATTENUATED WAVELENGTH FOR URBAN HYDROLOGICAL MONITORING

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To be useful, the monitoring of rainfall distribution above urban and surrounding areas need real time and high spatiotemporal resolution data. The purpose of the paper is to demonstrate that this requirement can be satisfied from a polarimetric radar working with a short attenuated wavelength. The algorithm to be used with such a radar, to retrieve the rain rate distribution, is based on an iterative scheme constrained by the integrated rain rate along the radar beam, deduced from the differential attenuation (or the differential phase shift) between the two linear horizontal and vertical cross polarizations. The method do not depend on the radar calibration (i.e. it does not require to be associated with a ground raingauge network). The validity of the method is illustrated by results obtained with a 35 GHz polarimetric radar working with the above mentioned algorithm and a 3 GHz carefully calibrated radar giving a background for comparison.

USE OF WEATHER RADAR FOR COMBINED CONTROL OF AN URBAN DRAINAGE SYSTEM AND A SEWAGE TREATMENT PLANT

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In present practice design and operation of urban drainage systems and the corresponding sewage treatment plant is done independendly. In this paper an approach is presented, the objective of which is joint operation of the urban drainage system and the sewage treatment plant at the end of the drainage system. This operation will be based on real-time flood forecasts which are computed with the aid of radar rainfall measurements. The goal of this control is to minimize the combined negative effects of the hydraulic load and the pollution load in the receiving waters. In order to make this control efficient precipitation information is required with a high resolution in space and time since already small differences of precipitation input into a rainfall runoff model result in large differences in computed runoff. The computed real-time flood forecasts have to be rather accurate at short-term (up to two hours) and maybe less accurate at medium-term predictions (based on weather radar and satellite data). For the real-time short-time forecasts the data obtained from one radar will be adequate while for the medium-term composite radar images from several radars will be required. The paper describes the theoretical approach and shows first preliminary results.

WEATHER RADAR DATA FOR REAL-TIME URBAN DRAINAGE SYSTEM MODELLING

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Predictive real-time control (RTC) of Urban Drainage Systems (UDS) requires computationally efficient and fast real-time UDS models and high-quality rainfall forecasts. This paper introduces a UDS modelling approach known as RHINOS, which uses distributed rainfall data to forecast flows at locations throughout the strategic pipe network. This new approach differs from existing urban hydrological modelling approaches in (i) the novel way in which the UDS is represented; (ii) the algorithm used for model parameter identification, and (iii) the strategies associated with the system output prediction. RHINOS has been developed and applied to an urban catchment in the north west of England of strategic importance. A case study for the UDS shows how high resolution (2 minute, 250 m) radar rainfall data from a C-band radar developed specifically for urban hydrology are used to predict flows in the urban system. A crucial phase in the production of high quality rainfall estimates over urban conurbations is the pre-processing of the radar reflectivity data. The paper describes a new approach for clutter removal known as moving window clutter suppression. The results are discussed in detail and the potential for high resolution radar rainfall data evaluated.

TOWARDS A STOCHASTIC MODEL OF RAINFALL FOR RADAR HYDROLOGY

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Research towards the application of combinations of weather radar and networks of rain gages for estimating the spatial and temporal variability of rainfall over both urban and rural catchments has been going on for almost two decades now. Radar and rain gages are thought of as complementary measurement devices, as the former essentially provides point measurements in time and integrated measurements in space, whereas the latter provide point measurements in space and integrated measurements in time. The basic assumption behind all sorts of more or less sophisticated statistical procedures for 'optimally' combining radars and rain gages has generally been to assume that rain gages provide 'ground truth' measurements. The main advantage of radars over rain gages, namely the complete spatial coverage they provide, is then used essentially to interpolate between the rain gage measurements. However, it is now more and more understood that neither rain gages nor radars provide 'the truth and nothing but the truth' when it comes to rainfall measurement. We maintain that the true nature of the discrepancies between radars and rain gages can only be fully understood if rainfall is regarded as a discrete process consisting of individual raindrops with different sizes and fall speeds. We have developed a very simple 'shaft' model of rainfall based on stochastic point process theory which captures the essential features of the discrete nature of the rainfall process and of the radar and rain gage measurement processes. Although the model can be made more realistic by increasing its level of sophistication, in its present form it already provides some interesting insights. Moreover, the simplicity of the model allows many results to be derived analytically without having to rely on Monte Carlo simulations.

ATTENUATION CORRECTION FOR WEATHER RADAR DATA: THE AMBIGUITY PROBLEM

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Estimation of rainrate from radar measurements at short wavelengths (X-band or C-band), requires to correct for rain attenuation. Retrieval procedures have been developed for rainrate estimation from attenuated measurements (e.g., Marzoug and Amayenc, 1994). However, they make use of different parameters (e. g., parameters of the Z-R and k-R power law relations, radar calibration error, 'blind-range' attenuation...) which, most of the time, cannot be known exactly. The aim of the present communication is to study the ambiguity problem related to the fact that the same measured reflectivity profile can be produced by several rainrate profiles, depending on the assumed values of the parameters. The following approach is used: for a given measured reflectivity profile, the corresponding rainrate profiles can be analytically expressed as a function of the attenuation model parameters. This analytical formulation makes possible to study the sensitivity of the rainrate profiles to the parameters of the attenuation model for their range of variation. It is shown that the set of ambiguous rainrate profiles is large and that measurement of the total path-integrated attenuation could allow for solving the ambiguity of the attenuation correction.

HS14 Hydrological models for agricultural catchment management

Convener: Cunnane, C.
Co-Convener: Damaskova, H.

A NESTED APPROACH TO THE INVESTIGATION OF THE HYDROCHEMICAL RESPONSE OF A COASTAL AGRICULTURAL WATERSHED TO NUTRIENT LOADING

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Water quality in estuarine and coastal environments is the result of pollution sources and land use changes in the river basin drainage areas. Yet evaluating the combined effects of pollutant transport and transformation, and changes in land use is a difficult task, especially when dealing with large and mixed land use watersheds.

A nested approach using information obtained both with field measurements and model simulation at different scales has been used to study nitrogen loadings to a shallow coastal lagoon. The upland watershed ranges between 1 and 3 metres below the sea level, and the water balance is highly determined by the pumping system and the channel network needed to drain the land. Leaching of N-fertilizers has been measured at selected points (maize fields at one-hectare scale) during and after the crop cycle. Soil hydrodynamic properties have been determined both in-situ using a tension-disc infiltrometer and with laboratory experiments. These measurements have been used to calibrate a deterministic model (DAISY) simulating water and N-dynamics in the root zone under various management practices. By using MIKE SHE and GIS, the data have then been integrated into a whole catchment model taking into account the spatial variability of the governing transport parameters.

IMPACTS OF LANDSCAPE MANAGEMENT ON THE HYDROLOGICAL BEHAVIOR OF SMALL AGRICULTURAL CATCHMENTS

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Changing land use induces different hydrological behavior of agricultural catchments. The runoff production in winter for example depends on the vegetation cover and the surface roughness which are influenced by management techniques. Therefore a new model system is presented which considers the consequences of those changes on hydrology. The physically based model system consists of two main simulation units: an one-dimensional Soil-Vegetation-Atmosphere-Transport model (SVAT) for evapotranspiration, infiltration and ground water recharge, and a hydrological catchment model for surface runoff and channel flow. In additional to observed changes in crop calendars of the last 15 years, the investigations contain scenarios such as land use changes implemented by new European Union guidelines, re-establishment of creeks, reforestation and applying alternative farming techniques.

MODELLING GROUNDWATER LEVELS IN A DRYLAND AGRICULTURAL CATCHMENT IN SOUTHERN ZIMBABWE

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Shallow weathered aquifers are currently the focus of increased development in rural areas of Zimbabwe. However, there is little evidence of the long-term behaviour of these aquifers and, in the early 1990s, falling groundwater levels and reduced dry season river flows were widely cited as major problems. Changes in land management, particularly deforestation and overgrazing, and variations in rainfall including a series of drought years have been proposed as the causes of hydrological change. In this study, daily rainfall records were used to simulate variations in groundwater levels over the period 1953-96 in a dryland agricultural catchment in southern Zimbabwe. The ACRU model was used to simulate the soil water balance with an additional model to predict groundwater fluctuations in the shallow aquifer. The models were validated against detailed measurements in the unsaturated and saturated zones. Long-term trends in simulated groundwater levels under current rainfed cropping practice reflect the response of the aquifer to cycles of above- and below-average rainfall. After a series of wet years in the late 1970s, simulated average groundwater levels at the end of dry season were almost three metres higher than in the early 1990s when minimum levels were modelled after an unprecedented run of poor rainfall seasons. These results indicate the dangers of misinterpreting short data records and of underestimating the importance of climatic fluctuations, in addition to the effects of land management on change in dryland environments.

ACCOUNTING FOR SUB-GRID HETEROGENEITY THROUGH AGGREGATION OF INPUT PARAMETERS IN A CATCHMENT SCALE WATER BALANCE MODEL.

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Issues related to scale are recognised as crucial in hydrology today. In response to this, a number of researchers have attempted to account for sub model-scale heterogeneity using a variety of methods. We present here a new methodology based on sound physical principles. The UK Meteorological Office Rainfall and Evaporation Calculation System (MORECS) has been improved and applied across a 1km grid overlaying a small agricultural catchment. This has enabled the variation in both soil and plant properties to be explicitly accounted for. Soil and plant evaporation is estimated by applying the Penman-Monteith equation over a four layer soil model which accounts for dynamic root growth. In addition, rainfall interception and surface runoff submodels have been added to estimate all water balance components. The above ground plant parameters are aggregated according to relative areas and equilibrium saturation deficits. Four root layers for each vegetation type are then superimposed to provide aggregate sub-surface plant parameters. Finally empirical equations are applied to mixed soil texture fractions to derive aggregated soil parameters. The model has been shown to replicate results obtained from other approaches at their application scales while having the potential to physically account for sub-grid heterogeneity at larger scales.

ANION MOVEMENT IN UNSATURATED ZONE OF HYDROMORPHOUS SOIL ON GNEISS

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Sulphate, nitrate and chloride ions were estimated in drainage and surface stream water. Seasonal course of NO_3 concentration in streams differs from that one in humus horizon solution. Shallow aquifers are saturated in winter and increase the NO_3 concentration for all the year. High SO_4 was found during the flow through the preferential pathways when GWL raises. High NO_3 flows during the GWL decrease. NO_3 ion is located in the small pores out of preferential pathways where SO_4 is sorbed. The higher the GWL increases the higher is the subsequent NO_3 concentration in streams. More frequent flooding of soil profile causes more intensive NO_3 leaching in wet year 1995 in comparison to dry year 1994 despite ofless intensive nitrification under wet condition in humus horizons.

VALIDATION OF A SIMPLE MODEL TO DETERMINE REGIONAL EVAPOTRANSPIRATION AND GROUND WATER RECHARGE RATES

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During the 1996 EGS symposium in The Hague the author proved that for the determination of daily evapotranspiration and ground water recharge rates the simple bucket model SOWAS showed results which were better or as good as the more complex, Richards' equation based model SWATRE.

The current presentation emphasizes the validation of the (calibrated) model SOWAS. Simulations were performed for 33 measuring points with different crops and soil types over a period of more than one year. Without changing any parameter value, the average deviation in soil moisture between measured and calculated values is less than 4 Vol.-%. Therefore the assumption is justified that only the field capacity, the rooting depth, the layering of the soil and one plant-specific parameter are sufficient to assess evapotranspiration and ground water recharge.

Furthermore, it will be shown that different types of vegetation affect much more the results than various soil types. Regional values and an areal distribution of the fluxes are easy to perform with (carefully chosen) soil-vegetation-classes, which can be detected by the combination of the soil- and the vegetation map. This is easy to apply and so, for instance, an optimum solution for plant water consumption strategies can be found.

VALIDATION OF CHAIN_1D NITRATE MOVEMENT SIMULATION RESULTS IN FIELD CONDITIONS

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The study has been done for the Cernici catchment in the Czech Republic for 1993, 1994 and 1995 years. Measured nitrate concentrations in water samples taken at several sites of the drainage system and in the stream have been compared with simulated nitrate concentrations at the bottom of two soil profiles (Dystric Cambisol and Dystric Planosol) under two type of bottom boundary condition (free drainage and variable pressure head) using CHAIN_1D. In general, the simulations under the variable pressure head bottom boundary condition provide reliable results in 1993 and 1994. The simulations under the free drainage bottom boundary condition significantly underestimate reality for whole period 1993-1995 and the courses of simulations show decreasing trend in time. On the other hand, the simulated data series correlate well with the observed data series for separate years.

APPLICATION OF A TWO-DIMENSIONAL MODEL TO CALCULATE WATER BALANCE OF AN AGRICULTURAL HILLSLOPE

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The objective was to simulate runoff production on an agricultural hillslope in Southern Finland. Water balance was calculated using a two-dimensional model describing vertical and longitudinal water movement along a hillslope strip. The model accounted for the production of saturated overland flow on the exfiltration part of the hillslope. The hillslope strip represented an elementary component to subdivide the agricultural catchment into hydrologically similar areas. The model results were assessed against measurements of surface runoff, subsurface drainage flow, and water table level, which were available at individual field sections for years 1995-96. Intensive runoff events during spring snowmelt and autumn rainfalls were the primary focus in the modeling application. The role of farming practices in the runoff production was discussed.

SIMULATION OF NITRATE LEACHING AT DIFFERENT SCALES IN AN AGRICULTURAL WATERSHED

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The use of numerical simulation models is mostly focused on local studies, due to the limited availability of input parameters and the required simulation time. Hence the aim of this poster is to demonstrate the possibility of simulating the nitrate leaching at different scales with a minimum of input information.

For field scale simulations the comprehensive data of the La Cote Saint André investigation site [France] was used. Input parameters were derived using regression functions. For example: pedotransfer function [PTF] was applied to describe the soil retention curve. The model [Opus] was first validated at a local scale.

At the catchment scale [Bièvre watershed] the results of the field scale simulations were taken into account. A loosely coupled approach between the geographical information system [GIS] and Opus was realized. Necessary model parameters were also derived via transfer function using the digital information of the soil and land use maps.

The different simulation results will be discussed with regard to spatial soil variability and time and spatial resolution of weather boundary conditions. The resulting "error maps" give an indication of the simulation accuracy.

DEVELOPEMENT AND APPLICATION OF A SIMPLIFIED, PROCESS ORIENTED RAINFALL RUNOFF MODEL

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A process oriented, distributed rainfall runoff model is applied to an agricultural catchment in Germany. Simulations with the calibrated model form the base for the developement of a simplified method.
For this method the catchment area is split into two domains: the 3-dimensional **convergence domain**, which consists of all grid cells around the drainage line with merging flowpaths. The complete model is used to simulate the runoff process within this domain. The **hillslope domain** consists of 2-dimensional hillslopes, which drain into the convergence domain. Runoff generated on those hillslopes is estimated by a simplyfied method, which is based on the flowtime as parameterization of topography. The results of a few calculations with typical land use, soil and soil moisture distributions are tranfered to all hillslopes.
In that way, the area, which is particularly important, is modeled in detail, whereas the less important areas are lumped together by a simplified approach.

A SEASONAL LONG-MEMORY STOCHASTIC MODEL FOR THE SIMULATION OF DAILY RIVER FLOWS

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A classic approach for performing water resources management procedures to be used in agriculture consists in simulating the water flows by means of a stochastic model. The capability of generating synthetic series of data allows to obtain many equally-likely hydrologic series, that can be used to test different management policies. However, this method is difficult to apply on daily river discharge data, which are often non-Gaussian and affected by long-memory, seasonality and non-stationarity. A fractionally differenced ARIMA model with periodical parameters is presented in order to face the problem. The correlation structure of the proposed model exhibits long-memory and can be varied along the period of the seasonality. This seasonal formulation is able to model either Gaussian or non-Gaussian data, it is asymptotically self-similar and converges to linear fractional stable noise after large aggregation. The estimation of the periodical parameters is carried out performing an approximate maximum likelihood approach. An application to the daily flows of the Po river at Moncalieri, in Italy, is presented, showing that the proposed model is able to reproduce the autocorrelation function and the probability density of the sample data.

Soil loss estimation for agricultural catchments

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The paper reports on field investigations and methodology carried out to make an erosion risk map of a small agricultural catchment (about 100 ha). A simple methodology for mapping and monitoring soil loss at regional scale is proposed. It is mainly based on the discretisation of the watershed into regular grids (of 5 m size), and on the integration of different erosion factors into a Geographic Information System (GIS).

A computer algorithm to calculate the Length and Slope factors over a two-dimensional landscape is used. This computer procedure has the advantage that it can easily be linked to GIS software such as IDRISI. The resulting erosion risk map shows a reasonably good resemblance with the intensity of soil truncation observed in the catchment.

TESTING OF AGNPS MODEL APPLICATION IN SLOVAK MICROBASINS

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The aim of the paper is 1. to test the possibility of AGNPS model (complex process oriented model for sediment and nutrient loading in surface water) application in specific geographical conditions of Slovakia and 2. to simulate runoff and nutrient loading (nitrate, phosphorus) in surface water in two experimental microbasins (forested, agricultural) during extreme rainfall events.
AGNPS is a single-event, lump-sum parameter, pollutant loading computer model. The possibility of AGNPS model application was tested in two experimental microbasins Rybárik and Lesný (Central Slovakia) where the necessary data were collected. The measured nitrate and ammonium concentrations in few minutes intervals were available in these basins during several rainfall-runoff waves. Therefore it was possible to compare measured and simulated runoff and loading. The result of the comparison is that the AGNPS model can be used for runoff and nutrient loading simulation during single rainfall-runoff event in studied basins with sufficient accuracy.

A DECISION SUPPORT SYSTEM FOR HILL RESERVOIRS IN THE SEMI-ARID ZONE OF THE MEDITERRANEAN PERIPHERY

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In the Tunisian State, it is proposed to build a thousand small hill reservoirs (10 000 to $1x10^6$ m^3) by the year 2000. There are currently 250 such reservoirs. Benefits of these reservoirs are seen in the form of flood protection of cities and infrastructure downstream and increased availability of water for humans, livestock and agriculture which in turn promotes the economy.

This project, which is funded by the European Union, will attempt to develop a decision support system for the construction and efficient management of these types of reservoirs which in turn requires a sound hydrological study of the region. Sediment transport, rainfall-runoff and infiltration models will be assessed and the most appropriate models chosen bearing in mind the availability of data. Working with EU partners, several experimental sites will be chosen and a data collection scheme instigated. It is expected that results of the project will be used will useful to Mediterranean policy and decision makers, hydrologists and farmers.

TESTING AGNPS FOR SOIL EROSION AND WATER QUALITY MODELLING IN AGRICULTURAL CATCHMENTS IN HESSE (GERMANY)

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Until recently, no suitable computer model was available to quantify P and N yields of nonpoint sources into surface water in Central German watersheds. The event-based erosion and nutrient transport model AGNPS (Version 3.65), developed in the USA, was adapted to Central German landscape conditions and linked to a GIS. Drawing on a two-year program of water quality measurements and on hydrologic data collected over 33 years, this modified model was tested in two medium-sized agricultural watersheds in the state of Hesse (Germany). With deviations of 1.7% and 3.8%, runoff volumes for all observed and simulated flood events showed a high level of agreement in both watersheds. Peak flows showed larger errors averaging 14.8% and 24%. Only for one of the two watersheds were sediment and total phosphorus yield computed satisfactorily, with average errors of 5% (sediment) and 6% (total P). Deviations for the second watershed were considerably greater. The same is true for the dissolved P and N yields. In the case of small events, AGNPS consistently overestimated the particulate P yield in both watersheds. However, the model correctly registered the overall dynamics of the system as well as the differences of sediment and total P yield between the two watersheds. The modified AGNPS model can thus be employed by environmental agencies as a useful planning tool.

LISEM, a catchment-based model to evaluate land use scenarios on minimizing soil and water erosion, and a related cost-benefit-analysis

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To arrive at optimum effective measures to reduce soil erosion in watersheds, a model has been developed that is capable of predicting water discharge and soil loss under different land use systems. Water discharge and soil loss from three catchments have been monitored during the years 1992 and 1993 at the main watershed outlet and at two other points within each catchment. Additionally, four hillslopes were instrumented and measurements of hydraulic heads from 2.5 cm up to 180 cm below soil surface took place. Measured data were used to calibrate and validate the physically-based hydrological and soil erosion model LISEM. With this model, several land use scenarios were calculated and judged on their effectiveness to reduce water and soil loss. For an overall best scenario a combination of management and construction measures appeared the best solution. For a few promising scenarios a cost-benefit-analysis has been carried out. It proved that the scenario with 'mulch' sawing on slopes steeper than 2% is the cheapest solution to reduce water and soil loss, and the scenario with additional grassed waterways in the valley and field strips on the hillslopes is most effective.

HS15 Minewater pollution: prediction and remediation

Convener: Younger, P.L.
Co-Convener: Fernandez, F.P.

Effects of mine waters on surface water quality

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HS15 Minewater pollution: prediction and remediation

Mining activities have a long time tradition in Slovak Republic. Due to low financial profit some of the mines were abandoned recently.

In the framework of national monitoring of surface water quality significant deterioration of water quality in Smolník creek was observed. This situation was caused by closed mining plant. This plant has been flooded and acid mine waters penetrated to the surface water.

As a consequence of decreasing in pH values in Smolník creek (pH min. value was 3,2), content of heavy metals increased immediately. These changes in surface water quality were observed also after confluence Smolnik with Hnilec river as the tributary to reservoir Ružín.

The will present the development of water quality in the affected area since 1986 and also the design of remediation measures:

- collecting of mining waters into one place (to facilitate the further handling with them)
- drilling of draining mining level
- filling up the vertical mining plants with carbonate rubbles
- draining of surface waters
- revitalization of Smolník river channel

Improved Simulation of Groundwater Rebound in Abandoned Mines

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The recent large-scale closure of most of the deep mines in the United Kingdom has lead to increased interest in predicting long term pollution problems. Large scale contamination of surface water and groundwater is expected as minewater emerges at the surface following groundwater rebound. An example in North East England is the Durham coalfield where pollution is expected to affect the River Wear, which is currently used for public water supply. Groundwater rebound will occur if the pumping of minewater from interconnected, disused workings is stopped. In order to predict the location, time of appearance and quality of minewater discharges, an existing physically based hydrological modelling system (SHETRAN) is being coupled with a pipe network model. Existing groundwater models cannot simulate the turbulent flow regimes thought to exist in large openings in mined systems such as roadways and uncollapsed workings. The application of a pipe network model will allow this type of flow to be explicitly simulated. It is hoped that this modelling system, once fully tested and validated, will provide a powerful simulation tool for investigating scenarios where good data are available and accurate, precise predictions of minewater problems are required.

SIMULATING THE EVOLUTION AND CONTROL OF ACID MINE DRAINAGE: A CASE STUDY OF MULTICOMPONENT REACTIVE TRANSPORT

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Groundwater systems downgradient of mine tailings impoundments can be impacted by acidic effluents carrying multiple contaminants including heavy metals. A sound understanding of the reactive processes, including sulfide oxidation and acid buffering, is required in order to determine the need for remediation measures. A multicomponent reactive transport model which couples kinetic sulfide oxidation and equilibrium speciation to advective-dispersive mass transport has been applied in a 2D vertical cross-section to the aquifer at the pyrrhotite-rich Nickel Rim tailings impoundment near Sudbury, Ontario, Canada. The site is characterized by low-pH conditions within the tailings, high concentrations of dissolved oxidation products within the tailings and the downgradient aquifer, and sequential pH-buffering by carbonate minerals, ferric oxyhydroxides and jarosite. The numerical model, incorporating 14 aqueous components and 10 solid minerals, was calibrated to depth-profiled field data of pH, Fe(II) and SO_4 representing 36 years of oxidation. Predictive simulations to 75 years show that as sulfide minerals in the oxidation zone of the tailings are depleted, Fe(II) and SO_4 in the aquifer gradually recover to near-background concentrations. The extent of acid neutralization and the fate of dissolved heavy metals is shown to be highly dependent on tailings mineralogy, moisture content and oxygen diffusion rates, with important implications on predictive uncertainty and the selection of remedial alternatives.

PRELIMINARY DATA THE GLOBAL HIDROGEOCHEMICAL CHARACTERIZATION IN THE TINTO RIVER BASIN.

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The Tinto river is a very polluted river because of the working of the sulphide mines in its basin. The upper part of their common basin(4000km2) includes possibly the largest sulphide mineralization in the world (Iberian Piryte Belt).The Rio Tinto Massif Sulphide Deposit contained about 1000 Mt of sulphides. The mines have been extensively worked on since the Chalcolithic until the roman period and the 19th century until our days. As a consequence of the weathering the pirite is combined together with the oxigen,water and helped by microbial processes, thus hence acid mine drainage.These acid mine drenage with very low pH variying from 1.5 to 2.5, along 83km from its source zone down to the estuary zone. These acidic mine waters are metal-rich, contain extremely high concentration ranging from 70-500, 20-150, 10-80, 0,5-15, 0,3-3 and 0,2-2,5 ppm for Zn,Cu,Mn,As,Cr,Cd, respectively for wed and dry climatic period. Furthermore, the sediments of the 70km. basin depict high trace-metal concentration about thousands of ppms for Fe,Cu,Zn,Pb,As.In order to treat all these problems, we are treating to search for possibles solutions the great serious dammages in environment (basin and estuary).We are making a global evaluation of all factors that are present in this questions such as climatology, sea-levels, hidrology, pollution-point, chemical analysis for to obtain possible conclusions for the resolution of this problem and the future recuperation of this area.

CONTROLLABLE CONDITIONS FOR THE POST CLOSURE PERIOD OF MINES IN KARST ENVIRONMENT

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The sensitivity of karstic aquifer systems requires considerations on the potential risks and on the appropriate control measures for the post closure period of mines. However the final decisions on the necessity of control and on the proper control measures shall be taken later, the actual closure measures should ensure the proper preconditions and decision's freedom for control measures to be made in the future. The coal mines, that have operated or are operating in the tectonically pre-formed sedimentary basins of the karstic limestone-dolomite bedrocks (e.g. in Hungary, in China and in Slovenia) should be regarded as existing or future waste water stores in/near the karst aquifers. Many toxic components were detected in the water of the abandoned cavities, however the acidic contents are usually not important. In lack of natural bottom-barriers and in presence of water inflow channels intersecting the barriers, long lived hydraulic connections exist. (Strong evidences are available on the longevity of inflow-channels in the bottom barriers.) The pollution shall appear decades later, because the water-head's rebuilding takes decades. According to the estimations the future gradient-manipulation, that can prevent against the pollution requires quite small output volume and yield to be pumped and processed. The observed longevity of old workings allows to apply this measure even more decades after the mine's closure. The proper preconditions for future gradient manipulation can be produced during the closure procedure without important extra costs.

ATTENUATION OF SULFATE AND HEAVY METALS FROM ACID MINE DRAINAGE BY PRECIPITATION OF ALUMINUM HYDROXIDES

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The oxidation of pyritic slate material in the Thuringian Slate Mining Area and subsequent formation of AMD affects the receiving waters with high loadings of Al, SO_4, H^+ ions and Cu, Zn, Ni and Mn. When mixing with nearly neutral tributaries the acid waters are partially neutralized leading to the formation of white aluminum-rich precipitates which cover the river bed for many kilometers. Hypothesizing the formation of basic aluminum sulfates like Basaluminite or Jurbanite, the binding of SO_4 to these precipitates was studied by analyzing the composition of water and precipitate samples. Additionally, the sorption of heavy metals to the precipitates was investigated. Sulfate is weakly bound to the solid phase and can easily be replaced by OH^- ions. Thus, the SO_4 content of the precipitates depends on the pH. At low pH values (4.8) the S/Al ratio corresponds to the theoretical ratio in Basaluminite (0.25) and decreases with rising pH. The precipitates are assumed to consist of aluminum hydroxide with SO_4 being adsorbed to the surface although a formation of Basaluminite at low pH values cannot be excluded. The concentration of Zn, Ni and Mn is almost not affected by the precipitation of Al. In contrast a maximum of 30% Cu is coprecipitated with Al at pH 5.5 and bound in a non-exchangeable form.

APPROACHES IN COMPLEX MODELING OF HYDROGEOCHEMICAL DEVELOPMENTS OF LIGNITE DUMP PILES

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UFZ investigates the development of open-pit mining dump-piles of central-german lignite district. The goal is to setup a prognosis of development of such regions. A ground- and soilwater monitoring system was installed and will be compared with controled lysimeter tests. Different column experiments in lab scale were carried out to identify the hydrogeological and geochemical development of spoil. Sulfur and carbon isotopical investigations were used for differentiation of organic and inorganic geochemical processes. Geophysical methods were applied to map the three-dimensional structure and texture of the refilled dump areas. A digital three-dimensional geological model will be prepared for handling the complex structure of such dumps. For the description of transient flow field it is necessary to imple ment a combined unsaturated/saturated and fractured/poreous model. This is the prere quisite for predictive reactive transport modeling. Studies have shown that field obser vation data and lab experiments have to be assessed carefully. Both hydrogeological and geochemical processes in dumps don´t seems to be in stabil equilibrium. The aim of this work is to show that dump piles can be succesfully described only by combination of geochemical, geophysical and hydrogeological investigations.

MODELING OF GROUNDWATERFLOW IN A PARTIALLY ABANDONED MINE WITH MODFLOW

J. Paulino (School of Mines of Oviedo)
F. Pendás and E.M.Casares (School of Mines of Oviedo)

Quantitative conclusions can be drawn using "traditional" modeling process with MODFLOW in describing fluxes of water in a mine, in a detailed manner. Here, it is considered how ceasing of pumping in a part of the mine affects the current explotation system carried out in the other part. Both zones are "isolated" by a protection massif, designed also for achieving the maximun "isolation" with the minimun loss of coal reserves.

A very exhaustive field work in the interior and exterior of the mine help to establish de water-circuit in the mine, the filling process and rise of water in the abandoned part and the location of the surficial mine water discharges.

Conclusions may help to desing the pumping system in the current workings through predicting the fluxes there and give some idea over the flood process.

HYDROLOGY OF DEPOSITS OF PYRITIC SLATE MINE WASTES CONTROLLING RIVER CHEMISTRY

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Acid mine drainage from slate mine tailings rich in pyrite in Thuringia, Germany, affects natural waters in this area. We found that a small river (pH 7, alkalinity $\approx$ 1.4 mmol/L) which flows through the bottom of a great dump of slate mine tailings, receives acid seepage which is neutralized at the confluent where aluminum hydroxides precipitate. The acidity which is generated by pyrite oxidation leads to weathering of the slate material, with subsequent release of Al, Ca and Mg and SO_4 as the dominant anion. During dry seasons these salts accumulate within the dump (dump outflow: pH $\approx$7). During heavy rainfall events the acid salts dissolve and are flushed into the river resulting in a pH decrease (pH $\approx$5). As the acidity load depends strongly on hydrological conditions, it is our objective to quantitatively describe the impact of catchment hydrology on river chemistry. At the dump, the rate of inflow and outflow of the river, precipitation, and the hydrochemistry of the outflow is measured. First results show a steep concentration peak of Al in the outflow when the discharge starts to increase, while the peaks of Ca, Mg and SO_4 are less steep, and their maxima appear simultaneously to the discharge maximum. After few days the salts are leached out. Using the modeling system AQUASIM, we are developing a model combining transport processes with chemical processes. After calibration with different sets of our data the model will be used to predict chemical responses to given hydrological inputs.

MODELLING MINEWATER FLOW AND QUALITY CHANGES AFTER THE ABANDONMENT OF UNDERGROUND MINEWORKINGS.

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Modelling minewater flow and quality changes is a method of predicting the nature of surface discharges of acid mine drainage. Traditional groundwater modelling techniques conceptualise aquifers as homogenous strata in which flow is laminar. The estimation of representative parameter values for modelling is hampered by the heterogeneity of the mineworking environment. This is particularly problematic when the strata being modelled has not contained water since prior to mining. Accepting the limitations of the data available, modelling is still useful when planning minewater pollution remediation. A lumped parameter model **GRAM** (Groundwater **R**ebound in **A**bandoned **M**ineworkings) has been developed as an alternative to traditional modelling techniques. It conceptualises a coalfield as a group of 'ponds'. Each pond is an area that has been extensively worked, which can therefore be considered a single hydraulic unit. The ponds are connected by roadways, modelled using pipeflow equations. The data requirements of **GRAM** are small, realistically aimed at the limited data sets that are available. Monte Carlo simulation of key parameters allows representation of both the uncertainty in estimation and the variability of the mineworking environment. The model output consists of probability distributions for volume of discharge, timing of first discharges and iron content. This form of output (rather than deterministic predictions) is a reflection of the limitations of the input data.

THE HYDROGEOCHEMISTRY OF A LARGE ABANDONED COALFIELD IN NORTHERN ENGLAND IN RELATION TO SUBSURFACE HYDROLOGY.

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Coalfield abandonment leads to profound changes in the subsurface geochemical environment, as ventilated, drained voids are flooded by rising minewaters. This change in geochemical conditions often has dramatic consequences for minewater chemistry, as highly soluble iron sulphate salts (the products of pyrite weathering) are flushed into solution by the rising water. Numerous geochemical reactions act to buffer pH in such systems; others lower it further. The abandoned Durham Coalfield in North East England displays the full range of possible resultant water types, from mature, neutral, brackish pumped minewaters, to acidic and/or ferruginous uncontrolled minewater discharges from workings which have flooded up to surface level. Pumped waters show evidence of ion exchange, and of mixing between fresh recharge waters and deep basinal brines in some areas. The most ferruginous pumped waters are associated with sump drainage in the Hutton Seam (a widely-worked, moderate- to high-sulphur seam). The chemistry of uncontrolled discharges is strongly influenced by pyrite oxidation (present and former), and in some cases by siderite dissolution.

HS16 Hydrology and water resources in the Danube region

Convener: Blöschl, G.
Co-Convener: Szolgay, J.

THE QdF MODELS FOR LOW FLOWS

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The QdF method, developed during the last years by CEMAGREF for the synthetical modelling of floods was tested for low flows, too. Using the experience in floods modelling, a specific methodology for low flows was developed for the Romanian basin Crisu Alb. The synthetical models are represented by the probability distribution functions of the hydrological variables described in terms of parameters such as averages (VCN) as a function of a period (d). In general, the diversity of the observed regimes was well reproduced by the proposed models. As the methodology QdF for floods, the information transfer is based on two local parameters of the low flow regime. The first parameter describe the most probable behaviour (the return period T=2) of the mean low flows (d=1) - VCN(T,d)=VCN(2,1). The other one, D, is related to the way the surface water is led from the water table during the drought periods - a parameter characterising the mean recession curve of the basin. Both parameters can be regionalized using multiple regression models. This methodology complements the classical methodology applied so far in Romania and in Danubian countries, offering new possibilities.

GIS AND REMOTE SENSING CAPABILITIES FOR THE EVALUATION AND MONITORING OF SNOWMELT RUNOFF IN CARPATHIAN BASINS OF ROMANIA

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The paper presents the operational applications in the field of snow hydrology developed in the Remote Sensing Lab of the National Institute of Meteorology and Hydrology in Bucharest, based on GIS and remote sensing capabilities.
The GIS developed for the snowcover water resources management includes information referring to the topography, land vegetal cover, landuse, soil types, hydrometeorological network and hydrological parameters.
The possibility of merging satellite imagery in the GIS allows the use of updating spatial information for land cover, landuse and also for the evaluation of basin parameters and for the snow cover and snowmelt runoff characteristics.
The paper discusses the methods developed for: basins snowcover areal extent and snowline elevation determination, new snowfalls identification, snowpack depth estimation, ablations monitoring and melting zones discrimination, snowpack water volume determination, snowcover depletion curves regionalization in the Carpathian basins. Based on snow accumulation and melting features, the characteristics of the runoff generated by the snow melting in some Carpathian basins of Romania are also discussed.

THE PROJECTS OF THE REGIONAL COOPERATION OF THE DANUBE COUNTRIES IN THE FRAME OF THE INTERNATIONAL HYDROLOGICAL PROGRAMME OF UNESCO

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The Danube basin is one of the most international river basins in the world, involving 13 main national territories. Hence, the hydrology of the Danube, where the whole basin is involved, is an extremely challenging task. At present, four projects are run, each of them covering the whole Danube catchment or the whole Danube reach. Most of them consist of a cluster of sub-projects dealing with the same main subject. The most important of them are project 5 "Update of the Hydrological Monograph of the Danube Basin" and project 6 "River bed conditions of the Danube". Project 5 consists of compiling an inventory of the main water management structures in the Danube basin, and of new analyses of the runoff regime and the water balance. Due to the complexity of these tasks, the input of data and relevant experience available within the countries is extremely important. It is shown that the present working procedure, involving the work on the project in a focal point, based on national data contributions in a predefined format, may be the most suitable way for achieving results in a multinational environment.

BOUNDARY CONDITIONS FOR INTER RIVERINE GROUNDWATER RESOURCES

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Depletion of groundwater resources was detected already in the eighties in the inter-riverine region of Duna-Tisza-Köze in Central Hungary. Among the causes of the drop in groundwater levels climatic variability, (over)utilisation of groundwater, changes in land use - mostly the increase of forest covered area, land reclamation and drainage were indicated. Beside qualitative judgement quantitative assessment of these factors is required. Precipitation induced infiltration presents source, evapotranspiration - sink and surface waters - third type of boundary conditions for groundwater. Meteorological elements varying with global and regional climate change directly interact with conditions of infiltration and evapotranspiration, regime of surface waters resulting in changes in the groundwater system. Investigation of the complex problem requires a comprehensive approach. An attempt is made to link separate modelling approaches into a versatile tool enabling to investigate the given section of the hydrological cycle and to answer certain practical questions arising in the given region and elsewhere with similar sensitivity towards groundwater problems. Results of General Circulation Models are scaled down to spatial and temporal resolutions allowing the linkage of models describing surface water budget, river flow, and groundwater.

HOW NEW SCIENTIFIC CONCEPTS CAN SUPPORT SUSTAINABLE DEVELOPMENT OF WATER RESOURCES IN THE DANUBE REGION

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During the last twenty years scientists have developed some new and promising concepts, approaches and ideas such as deterministic chaos, fuzzy logic, holistic approach, sustainable development etc. The gap between new concepts and their applications is still huge. Because of that time has come to change ideas and philosophy in the engineering practice. Water, as a crucial element for human beings and the environment is appropriate to be a starting point and link for taking this important step. Analysing complex socio-economic and ecological situations in the Danube region, especially in connection with water resources management, this paper tries to give some practical answers. Scientific, political and other sorts of cooperations exist between Danube countries, but their results are not satisfactory. There is too much of a looser-winner syndrome and short term profit pursuit in this cooperation. The paper discusses how new concepts can help us to manage water resources in the Danube region more efficiently.

REGIONALISATION OF MINIMUM FLOWS IN SLOVENIA

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The Hydrometeorological Institute of Slovenia maintains more than 160 stream gauging stations with different observation periods. We processed data for periods from 1965 to 1994 (65 gauging stations) and from 1980 to 1994 (82 gauging stations). The flow duration curves were plotted and the 50, 80 90 and 95 percentiles of daily discharges were derived for all of the gauging stations. We did the probability analysis with the same data and determined probabilities of 50%, 80%, 90% and 95% of yearly minimum discharges. Relationships between the yearly and daily minimum flows for different periods of time were investigated. The daily and yearly minimum flows calculated for different periods very well fit together and we found weighing factors for the probability values calculated from the different time periods. We also compared for the same stations yearly and daily minimum flows. The daily data with 95% of probability, correlate quite well with twenty years (95% of probability) minimum flows. Specific minimum flows (litre per second per square kilometre) with twenty years return period were calculated for the gauging stations with observation periods from 1980 to 1994 (82 stations). Data varied from 0,024 to 24,5 l/sec/km^2. The regionalisation of specific minimum flows was done by the national watershed coding system and GIS.

LONG-TERM WATER BALANCES FOR SUBCATCHMENTS AND PARTIAL NATIONAL AREAS IN THE DANUBE BASIN

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The Hungarian Research Centre for Water Resources Development (VITUKI) has compiled the last, synoptic chapter (Hydrological Balance) of the Hydrological Monograph of the Danube Basin, elaborated in international cooperation. The simplest type of multi-annual water balance, expressing the equilibrium of precipitation P versus evapotranspiration E plus runoff R, has been compiled for the period 1931--1970, first for 47 subcatchments and then for twelve partial national areas, as balance units. For each of these units the regional average values of the three balance components, expressed in mm yr^{-1}, have been determined by transforming the hdrological isoline maps (scale: 1:2,000,000), printed in 1984 in Budapest, into planimetric maps. The errors of balance do not exceed, with a few exceptions, the very favourable limit of ± 5%. As hydrologic characteristics, the runoff coefficients have been calculated for each balance unit both individually and as a longitudinal function of the whole Danube. The latter also includes the (cumulative) regional average values of precipitation and runoff for the catchment belonging to any arbitrary Danube section. With the help of this longitudinal profile it was possible to compare the discharges derived from the runoff isoline map with the corresponding values calculated from observed data series of Danube gauges. The result of this comparison was satisfactory, too. As water management characteristics for each of the twelve national catchment areas, the following indices have been determined: "own" surface water resources; relative contribution to the total water resources of the Danube basin; and the ratio of "own" to "transit" water resources.

HOW TO IMPROVE THE OUTPUT OF HYDROLOGICAL MODELS?

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Reliable model results need appropriate models describing the hydrological process, representative data and optimum parameters. (1) Non-linear models describe the process precisely, but the use of them is generally very complicated. Application of threshold(s) makes the linear models quasi-non-linear, and the results are also acceptable. The use of coupled deterministic-stochastic models is highly recommended to improve the results. Here an error correction sub-model is applied to model the uncertainties of the process. This sub-model can be a simply continuous error correction if the error sequence is highly correlated otherwise the Kalman filter is a good tool. (2) As far as the representativity of data is concerned the model results can be improved by the division of the watershed into sub-basins and by using more frequent observations. (3) The third possibility to get better results is to apply reliable model parameters. According to the results of sensitivity analyses the most sensitive parameters should be updated more frequently. The use of genetic algorithms is an excellent way of parameter optimization. Genetic algorithms are based on natural selection and the mechanisms of population genetics. Some case studies in the Danube region are presented in the paper.

TIME AND SPACE VARIABILITY OF DRY AND WET PERIODS IN EAST SLOVAKIA

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In this paper the time and space variability of dry and wet (or warm and cold) periods in the eastern part of Slovakia has been evaluated. As representative climatic and hydrologic characteristics, temperature, precipitation and discharges have been analysed. Deviations of annual means from the long - term annual mean for each year and each gage station have been determined according to the equation :

$$\Delta Z = \frac{Z1 - Z2}{Z2} \times 100 \ ,$$

where Z1 is the annual mean of temperature, discharge or precipitation; Z2 is the long - term annual mean of temperature, discharge or precipitation; and ΔZ is the deviation from the long - term mean [%]. The deviations represent Z-coordinates of the XYZ "space-time" coordinate system, where the gage stations (ranging from the west to the east of the region) represent X "space" coordinates, and the years of observation represent Y "time" coordinates. The deviations interpolated to the form of isolines interpret the occurrence of dry and wet (warm and cold) periods in space and time. The aim of the study is to discover if there is a possibility of compensation of surface water resources from one part of a region to another in the case of climatically or hydrologically dry periods.

A LARGE AQUIFER IN THE DANUBE FLOODPLAIN - ROMANIA

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The Danube floodplain sector, located between Corbului Island and Ismail Ceatal (Fork) covers, on the Romanian territory, lands of about 513.000 ha - out of which around 83% represent flood-controlled areas.
Based on its natural formation conditions, subjacent to floodplain alluvial deposits, a thick aquifer of gravel and sandy matters has been identified. The deposit height varies between 5...10 m upstream from Calarasi, 15...25 m at Cernavoda, and 30...40 m on the downstream sector (as a result of subsidence phenomena). The aquifer transmissivity ranges between $5*10^{-3}$ and 10^{-2} m^2/sec, according to local conditions. Annual aquifer recharge rate comes partially from rainfall (between 100...150 mm) and partly from inflows due to high Danube River levels; a head of 1 m above the average groundwater elevation, for example, generates a flow rate of $20*10^{-3}...25*10^{-3}$ m^3/sec. Outflows are mainly caused by either evapotranspiration (reaching 60% out of the total outflow at Corabia), or pumping outs (up to 80% of the total outflow at Braila).
The global yearly extracting potential of the aquifer, estimated at about 750 m^3/ha, represents around 10% of the total water storage contained in the gravel deposit.
The salt contents of groundwater ranges between $5*10^{-4}$ kg/m^3 upstream from Corabia and $1.5\text{-}2.0*10^{-3}$ kg/m^3 downstream from Cernavoda.
Both the quantitative and qualitative characteristics of Danube floodplain groundwater would recommend its aquifer as either drinking water or farm use water. Alternatively, it could supply an irrigated area of about 140.000 ha.

EXTREME SEASONAL PRECIPITATION IN MOUNTAIN REGIONS OF BULGARIA

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Besides the "normal" or the most probable events, extreme meteorological events are also fundamental elements of the climate. Knowledge of extreme event statistics, including event probabilities, return periods and design values, for various climatological elements is of great practical importance.

In the paper data for seasonal precipitation amounts were used for identification and fitting the desired extreme probability distributions. Data for seven mountain stations were used. The basic period was 1935-1995. The homogeneity of the time series was tested. The data were fitted by normal, gamma and lognormal distributions. The Jenkinson's method was applied to estimate the expected precipitation maxima for various return periods.

REGIONALIZATION OF MAXIMUM SPECIFIC SEASONAL DESIGN DISCHARGES ON SMALL CATCHMENTS IN SLOVAKIA.

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Estimation of design discharges on ungauged catchments has attracted great interest in Slovakia during recent decades.
Regionalization schemes represent a good tool for solving these tasks. To eliminate the heterogeneity due to the origin of flood events, the annual maximum peak discharges from 267 gauging stations were divided into two seasons, the summer and the winter season. A special methodology for determining the origin of each analysed event was derived and tested. The usage of a unified frequency distribution for all cases was considered, and the most convenient one was tested in order to arrive at unified data for the final comparisons of the regional analysis. The territory of Slovakia is extremely heterogenous in its geology and morphology, therefore, the regionalization of seasonal 100-year maximum specific discharges was based on regions according to catchment, geomorphologic and hydrogeologic characteristics. Finally, 18 regions were identified for which the seasonal 100-year design discharges could be derived. The proposed regionalization approach seems to provide a useful tool for the practical estimation of seasonal design floods in small ungauged catchments in the entire territory of Slovakia with an economically acceptable and hydrologically correct safety factor.

RECENT DEVELOPMENTS IN MODELLING THE SPACE-TIME VARIABILITY OF THE COMPONENTS OF THE WATER BALANCE IN TRANSBOUNDARY RIVER BASINS.

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Experience in using some models for the investigation of the space-time variability of the water balance components in large river basins is described. Conceptual and water balance models were used to estimate the space-time dynamics of the main water balance components. Different efficiency criteria for each model have been applied. Time series of many years of standard hydrometeorological data have been used: air temperature, vapour pressure deficit, precipitation, snow cover, rainfall and soil moisture from daily measurements at the meteorological stations. The approaches described are important not only for scientific purposes but also for practical purposes including short-, middle- and long-term river flow forecasting for such large river basins as the Danube. Some of the models have been successfully operated in the NHMS of Ukraine. Other models will have been put into practice in the near future.

QUANTIFICATION OF SPATIAL AND TEMPORAL VARIABILITY IN SELECTED SOIL MOISTURE CHARACTERISTICS IN HUNGARY

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Long (1881-1990) series of soil moisture conditions characterised by two estimated parameters are investigated. These are (i) the standard Palmer Drought Severity Index (PDSI) and (ii) the estimated numerical series of soil moisture content (SMC) in the upper 1.0 m layer, both computed from monthly precipitation and air temperature data. Besides the derivation and comparison of some basic statistical parameters, two further aspects are tackled: First, spatial distribution patterns are determined by using factor analysis (FA). FA in S-mode is applied to determine geographical regions with inter-annual anomalies that appear similarly within a given region, but differently in the other ones. FA in T-mode classifies the characteristic types of spatial distribution in the individual months. The results of both FA modes are tested with respect to the number of stations and to the time interval, they are computed from. Second, time variability is characterised for the representative stations of each region, also derived from the FA, namely the (S)ARIMA-structure to characterise both intra- and inter-annual variability, and also the long-term trends. The latter problem is considered in connection with the global climate variations, too. Linear regression of the soil moisture parameters to the hemispherical mean temperatures and continent-ocean temperature contrast are computed. Significant negative regression coefficients in the warm period of the year project an increase in the frequency of droughts, if global warming continues.

SEDIMENT YIELD OF THE DANUBE RIVER AND DELTA FORMATION

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River sediments play a dominant role in the Danube delta formation. During the last 250 years the most intensive deposition of the Danube sediments occurred at the Chilia branch mouth. Here so called the Chilia delta rapidly protruded into the Black Sea. By 1980 this delta had a surface area of 348 sq. km and a mean length of 19,3 km. New estimations of the sediment yield of the Danube River at its mouth have been made by the author. Over the period from 1921 to 1960 water runoff and sediment yield equaled 199 cu km/yr. and 67,7 mln. t/yr. respectively. During the same period the fraction of the Chilia branch was 62-66 % of the Danube flow. Since 1961 the sediment yield sharply decreased up to 42,2 mln. t/yr. It can be explained by the reservoir cascade construction in the Danube basin. The sediment balance equation for the Chilia delta for different periods, worked out and analyzed by the author, showed the following: 1)nearly all river sediments deposited in the river fan; 2)role of the sea sediments in the delta formation was insignificant; 3)the fraction of the river sediments remaining in the fan increased with the delta growth. During the last decades the Chilia delta growth slowed down. The main reasons were that the river sediment yield reduced and the fraction of the Chilia branch flow decreased from 62 % in 1960 up to 58 % in 1993.

VALIDATION OF A MODEL FOR ESTIMATION OF THE AVAILABLE SOIL WATER STORAGE

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In this study we used an evapotranspiration model (Budagovskii, 1964) to calculate the available soil water storage in a 1 m soil layer during frost-free periods with a 10 day time step. Standard observational data of agrometeorological stations (air temperature, air humidity deficit, wind speed, precipitation, net radiation) and leaf area index were used for the calculations. We have performed calculations for the spring wheat and corn fields of the forest-steppe and steppe zones of the Former Soviet Union (29 year-locations, or 328 points). Comparisons of the calculated values of the available soil water storage with the data measured at agrometeorological stations show that the systematic error does not exceed 4 to 5%, and the root-mean square deviation 7%. In doing this one should take into account that the measured values of the available soil water storage also contain errors due to a strong spatial variability. The root-mean square error of the measurement for different values of the available soil water storage was estimated from the literature. Notice that the root-mean square errors of the calculation and measurements are independent. That is why it is possible to estimate the root-mean square errors of the calculations. Analysis of the results shows that the model is suitable for calculating the soil water storage during frost-free periods with satisfactory accuracy.

SPACE-TIME VARIABILITY OF DANUBE RIVER FLOWS IN THE DJERDAP RESERVOIR

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The Djerdap (Iron Gates) dam is situated at the outlet of the Djerdap Gorge (at km 944). The reservoir is 225 km long. The main goal of the Djerdap I power plant is to produce the more possible peak energy, according to environmental constraints. At such operation of the power plant, unsteady flow in the reservoir (and downstream) is of particular interest. A mathematical model of the Djerdap system is developed within a study of the Djerdap power plant operation and its environmental impact. The results show that the Djerdap hydropower plants may be considered as run of river only if the river flow is 9600 m^3/s or more. According to the operation rule the daily average flows at the input and at the output of the Djerdap reservoir are equal. But, hourly values of flow vary at the dam from 2000 to 8000 m^3/s, for a daily average of 6000 m^3/s. Water levels at dam I vary ±0.5 m from daily average value, and at km 1075 (Nera) the variations are ±0.2 m. The relative variations at the dam decrease if discharge increases; also, variations decrease if distance from the dam increases. The space-time variability of Danube river flows in the Djerdap reservoir has to be considered in modeling and computing sediment transport, reservoir sedimentation control, or/and water quality control, particularly if the velocity is the principal determining variable.

The Water Budget Component Modeling

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Centers for primary data processing are six hydrological district offices which are supplied with appropriate PC software. The main data processing system consists of procedures that are developed for: processing discharge measurement data, water budget criterion controls, graph processing and year book publishing. This system has successfully been operated for several years.

This paper will present a new approach to the time and space scaling of water budget components. The relationship between precipitation and runoff is modelled by simulation techniques. Also the influence of different time bases in computations as well as the method of estimation of changes in storage is analyzed.

The availability of data in transboundary river basins is discussed in order to use the methods in large river basins. The cooperation between neighboring countries is needed for water resources assessment of river basins such as the Danube and its large tributaries.

THE CONDITIONING OF STREAM FLOW BY PRECIPITATION IN THE NORTH-WESTERN PART OF ROMANIA

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The north-western part of Romania includes river basins with different natural conditions. The conditioning of stream flow by precipitation is obvious but there are additional controlling factors such as: geology, density of the drainage system, and exposure of slopes. The correlation q=f(x) and the controlling factors are analysed in a region of more than 22,000 km^2 including river basins with areas between 30 km^2 and 15,000 km^2. A methodology for determining a geologic and a vegetation coefficient is presented which justifies the use of different relationships q=f(x) in different subregions. Finally the regions for which the relationships are valid are presented.

HYDROLOGICAL MAPPING OF WATER BALANCE ELEMENTS IN SLOVAKIA USING GEOGRAPHICAL INFORMATION SYSTEMS

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In this paper the quality of existing methods for the traditional spatial interpretation of the elements of water balance (precipitation, temperature, potential and areal evapotranspiration and elementary runoff) in Slovakia using hand-drawn isoline maps is analysed. The main purpose of the study is to verify the quality and consistency of existing hydrological maps. Existing methods for constructing hydrological maps are reviewed. The construction and use of raster (gridded) and vector-based maps in a geographic information system (GIS) environment is discussed. The advantages of the use of a digital raster-based interpretation of hydrological elements are evaluated. On the basis of existing interpretations of selected water balance elements (long-term average mean annual temperature, precipitation, evapotranspiration and runoff maps of Slovakia from 1931 - 1960), digital raster maps were constructed in a unified cartographic projection. The accuracy of the grid-based maps has been tested against station data. The quality and consistency of the maps have also been tested. The results indicate that the existing hand-drawn isoline maps do not form an exact and consistent system.The possibility of the use of automated mapping methods is tested and demonstrated with the help of simple spatial models.

METHODOLOGICAL AND DATA ASPECTS IN REASSESSING THE WATER BALANCE OF THE DANUBE RIVER BASIN

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The work related to a new version of the water balance of the Danube basin is presented. The project is part of the Regional Cooperation of the Danube Countries in the frame of IHP of UNESCO and is being prepared in close cooperation between Austria (TU Wien) and Slovakia (Water Research Institute, Bratislava). The new version of the water balance refers to the time period 1931-1995 and an internationally coordinated scheme of subbasins. The Water Research Institute as a partner is currently dealing with evaporation and runoff data and with the scheme of subbasins to be used. Problems of runoff data availability and the assessment of the runoff contribution of ungauged interbasins are discussed and possible solutions are shown. Specific questions or runoff data compilation related to the complex water balance of particular subbasins are demonstrated. A case study for the Nitra basin (Slovakia) draws the attention of the working team to the vertical distribution of hydrometeorological elements. Evidently, areal processing of these data needs to be done by GIS-technology.

INTERACTION OF RIVER AND SEA WATERS AT THE DANUBE MOUTH AND ITS DEPENDENCE ON NATURAL AND ARTIFICIAL CHANGES IN RIVER FLOW

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The study of the mixing zone structure and dynamics at the Chilia branch of the nontidal Danube River mouth has been carried out by the author on the results of 21 surveys of the salinity distribution in the surface layer at the open nearshore, river discharge data and wind observations during 1961-1983. According to the character of the longitudinal (seaward) changes in salinity three zones are distinguished here: the zone of through-flowing fresh river, the mixing zone of river and sea waters, including the hydrofront, and the zone of sea waters. For approximate calculations of the salinity distribution at the surface as a function of the combined effect of water discharges and wind with certain time in advance the regression equations were obtained. Regression analysis showed the time lag up to 30 days between discharge oscillations and the corresponding salinity changes offshore. The effect of the wind on different parts of the buoyant plume is very complicated. Compared to west-east winds broadening the plume and inducing vertical mixing in the layer from 5 to 15 m, north-south ones are less effective in driving the buoyant plume at the nearshore. Obtained quantitative relationships between water salinity at the nearshore and discharges of the Danube river can be used for estimation of the influence of natural and anthropogenic changes in river discharge on the salinity distribution at the nearshore, for calculation of various dissolved substances concentration and determining of the optimum ecological conditions for the nearshore biota

STABILITY APPRAISAL OF RIVER CHANNELS

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The appraisal of channel stability is important in the investigation of fluviomorphological processes. The coefficients of stability, which have been determined by various authors (Lohtin, Velikanov, Makkaveev), were taken as a criterion for appraising channel stability. The indicators of stability were calculated by using the following parameters : slope of water surface, flow depth, fall velocity of bed load, average diameter of bottom-bed load, and average velocity. The results of the investigation permitted the classification of rivers by their degree of stability under natural conditions. Rivers with unstable and somewhat unstable channels freely refer to those classification. Undivided and relatively straight parts of rivers have stable channels and are observed in upper rivers, and in shortened sections of rivers that run across solid rock. Also, an appraisal of the horizontal deformation of channels was made, and the results matched well with the stability appraisal.
The influence of human activity on fluviomorphological processes was determined through plane surveys of parts of rivers during different years.

REGIONALIZATION OF THE MAXIMUM DISCHARGES IN THE DANUBE RIVER BASIN

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In the frame of the IHP-Regional Cooperation of the Danube Countries a project aiming to perform a spatio-temporal analysis of the maximum discharges has been undertaken. Relied upon 200 series of annual maximum discharges recorded over long periods (50-150 years) at representative gauging stations from the Danube basin the statistical parameters of the probability curves have been computed. Then, the nondimensional values $Kp = (Qp/Q-1)/Cv$ (Q - annual mean maximum flow, Cv - coefficient of variation, p - probability of exceedance) have been assessed and thereafter the relationships $Kp = f(Cv, p)$ have been established. These relationships have been regionalized for different physiographic representative zones from the Danube Basin and the ordinates Kp of the probability curves have been determined. A comparison between the regional probability curves and some usual theoretical ones has been done. Also, based on the peak discharges of the large floods recorded in this area, the enveloping curves $q_{max}=f(F)$ (q_{max} - specific maximum discharge, F - basin area) valid for the representative zones of the Danube Basin have been derived.

TIME-SPACE RELATIONSHIPS BETWEEN ANNUAL PRECIPITATION, DISCHARGES AND AIR TEMPERATURES ON THE TERRITORY OF SERBIA

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The paper presents the procedure for defining the time-space relationships between time-series of annual precipitation, discharges and air temperatures. The applied methodology is based on space-time analysis using the long-time series of observation data. Previously, the analysis of homogenity, trends and cycling had been done. The regional relationships have been developed on the basis of these results.The regional relationships are defined using very long period of observations of the climatological and hydrological gauging stations. The paper is illustrated with the most important general results of carried out regional analysis on the territory of Serbia.

HYDROGEOGRAPHIC REGIONAL TYPIFICATION - CATCHMENT APPROACH

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A hydrogeographic regional type is defined as a set of basic catchments which are not spatially contiguous, but show similarity from the point of such physical characteristics that ensure fulfilment of the condition of homogeneity of the hydrological response within it and heterogeneity among them. The basic methodological steps of hydrogeographic regional typification are as follows: i) the definition of a basic catchment and the division of the area under study into a set of basic catchments, ii) selection of basic catchments with hydrological measurements for further analysis in steps (iii - v), identification of the physical characteristics of basic catchments and controlling the spatial variability of the selected hydrological response,
iv) grouping of basic catchments into physical regional types on the basis of the characteristics quoted in step (iii), v) testing the heterogeneity of the hydrological response between identified physical regional types and the homogeneity within them vi) assignment of the rest of the basic catchments into identified hydrogeographical regional types vii) estimation of the hydrological response for the population of basic catchments of the hydrogeograhical regional types on the basis of a set of selected basins.

SUBSTANTIATION OF A EVAPORATION FLUCTUATION MODEL FROM A WATER SURFACE

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Studying the regularities of temporal changes in evaporation from a water surface is necessitated by water management. Unconditional distributions of the probabilities of evaporation from a water surface are investigated using field observational data and a calculated series. The analysis showed that the process of evaporation from a water surface is characterized by low temporal variability ($Cv<0,2$), whereas monthly evaporation is characterized by higher variability. The maximum Cv values are observed in May and October. Two areas with different Cs/Cv values are singled out within the excessive moistening zone. The three-parametric Kritskii-Menkel' distribution with corresponding Cs/Cv values can be recommended as an unconditional distribution for the excessive moistening zone and the normal distribution for the arid zone. A positive correlation between succeeding years is typical for the series of evaporation from a water surface. In the first approximation, using a simple Markov chain is recommended. Monthly evaporation values are characterized by a closer correlation than annual values, and the maximum correlation coefficients (0,7) have been recorded in the second half of summer.

HS17 Seepage from open channels

Convener: Blaschke, A.P.

BIOGEOCHEMISTRY OF DISSOLVED ORGANIC CARBON IN THE BED SEDIMENT OF THE WHITE CLAY CREEK (WCC), PIEDMONT, USA

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Conductance, dissolved organic carbon (DOC) and dissolved oxygen were measured in the interstitial water along the WCC stream during 1994-1996. DOC was consistently higher (2.100±1.331 mg C L^{-1}) in the surface water than in the interstitial water, where it declined from 1.084±0.647, 0.571±0.325 to 0.446±0.139 mg C L^{-1} over the sediment depths of 10, 30 and 50 cm, respectively. Based on an end member mixing analysis (EMMA) and using conductance as a potentially conservative tracer, we assessed the relative contributions of the surface water and the 30 cm intestitial water to the 10 cm water parcel. From this EMMA we then predicted the DOC concentration in the 10 cm sediment layer. The goodness of fit varied from 53 to 84% along the stream. Further, we considered observed DOC concentrations higher than the predicted ones as indicative for a DOC source in the sediment. This agreed well with an oxygen depletion higher than can be explained by DOC as the only carbon source. Our data suggest the 10 cm sediment layer as an important site of DOC generation from particulate organic carbon (POC). This process was found to be a function of the hydrological retention which we described by the Darcy approach as the vertical flux of water masses. Fluxes from the the 10 cm sediment layer to the surface water were highly variable and averaged 7.874 mg C $h^{-1}m^{-2}$ (±10.114 C $h^{-1}m^{-2}$).

ROLE OF BIOFILM PROCESSES IN THE CLOGGING OF THE DANUBE RIVER BED

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In an attempt to identify the main processes leading to clogging of the sediment in the Danube River (Vienna, Austria), biofilm esterase activity (FDA), bacterial abundance, microbial extracellular polymeric substances (MEPS) and total particular carbon and nitrogen were examined in sediment cores (10 cm layers down to 80 cm depth). FDA was very low and ranged from 7.6 - 88.5 μM FDA h^{-1} g^{-1} dry mass (DM) sediment (< 1 mm grain size). Bacterial density ranged from 1.0 x 10^7 - 1.2 x 10^8 cells g^{-1} DM. FDA and bacterial abundance correlated with the extracellular polymeric substances which are indicative for the biofilm matrix biomass. High spatiotemporal variability did not allow to detect any significant impact of biofilm processes on sediment clogging. Further investigations using a closer qualitative analysis of MEPS will help assess the role of biofilms in clogging.

HYDROLOGIC AND HYDROGEOLOGIC ASPECTS OF SURFACE/GROUND WATER ECOSYSTEM INTERACTIONS

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Earlier investigations on interactions in a surface/ground water system in the Danube wettlands has shown that seasonal water level fluctuations of the surface water induced drastical changes in the groundwater ecosystem. Recently, an intensified monitoring program in a smaler area of the infiltration zone was undertaken in order to better quantify the ground water recharge and the oxygen dynamics. A mathematical model helps to describe these processes. Differences in the clogging of the shore area and the infiltration through the soil surface have been taken into account. The numerical model approach explores also the dynamical distribution of subsurface organismal assemblages

CLOGGING PROCESSES IN SURFACE WATER BODIES - A PROBLEM ASSOTIATED WITH GROUND WATER MANAGEMENT

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In connection with the Vienna city ground water management system which is in operation, direct irrigation of the old river arms (in the management area) with bank filtrate from the Danube is forseen. Due to the elevation of the water level in these surface waters, it will be possible to counteract the lowering of ground water level, a major problem that was threatening the drying up of meadows and woods in the Prater Park area (an important landscape element of the city). The increase of water level in these water bodies can lead to intensified exfiltration from surface waters into ground water, which may in turn accelerate or modify the bed clogging process in the old arms. In order to evaluate the effects of clogging, an intensive water level monitoring and seepage measuring program was carried out in two steps: a) investigations on surface/ground water interactions under natural conditions (without irrigation) and b) with irrigation. These investigations were accompanied with parallel water quality assessment in an elaborate monitoring network. The results obtained were used for transient simulation runs of a two layer ground water model. Predictions were made about possible bed clogging during the recharging operations.

BED SURFACE CHARACTERISTICS AND SEEPAGE - OBSERVATIONS FROM THE RIVER RHINE

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Bed surface characteristics of the River Rhine have been intensively studied by means of two diving-bell watercrafts. The diving-bell or caisson does not only allow to examine sedimentary structures, grain-size composition, and macrobenthos directly at the river bottom but also to investigate deeper strata and the intersticial by drilling and sounding. Like in other navigable river major engineering works have concentrated both bed load transport and frequent bed-disturbance by barge traffic in the navigation channel with near bank regions developing distinctive sediment and macroinvertebrate assemblages. River bed clogging is confined to the more undisturbed regions but varies considerably in relation to extension and intensity with the seasonally changing hydrological conditions. Main types are mechanical and biological clogging or a combination of both wheras chemical clogging is found rather seldom. Enhanced clogging is observed in the vicinity of pumping wells especially where highly efficient horizontal wells are located in the bank region. Here an unsaturated zone can develop directly beneath the bed surface. In those cases seepage mainly takes place midstream or in the opposite half of the river. Due to the sedimentological conditions and the frequent barge traffic complete clogging over the whole width of the cross section does not occur in the free flowing section of the River Rhine.

SEEPAGE FROM SOIL CHANNELS: OPTIMIZATION AND ESTIMATIONS

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Minimization of seepage losses and other negative consequences (water logging, salinization of adjacent aquifers) was addressed as an important problem in irrigation practice [9] and first analytic solution to an isoperimetric problem was derived by Preissmannn [9]. We review our results in optimization of channels, their lining, spacing that provide extrema of a criterion (seepage rate, water table elevation at prescribed point, travel time of neutral tracers along stream lines) at prescribed integral hydraulic characteristics (cross-sectional area, hydraulic radius, wetted perimeter) and restrictions [1-4, 6,7]. Darcian, 2-D, steady seepage in different hydrogeologic conditions is assumed in modeling. New rigorous explicit solutions are discussed for seepage from a bed with cake of different conductivity [5] and for a cascade of channels which saturated zones overlap.

THE PREDICTION AND MANAGEMENT OF SALTWATER SEEPAGE FROM BRACKISH CANALS IN SOUTHEAST FLORIDA BY MEANS OF A NUMERICAL MODEL

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Salt water intrusion has been of concern in south Florida for quite some time. In addition to classical, horizontal oceanic intrusion, vertical infiltration of brackish sea water from the many open sea-canals have now become a major threat to the public water supply, particularly, since increasing water demands have lowered the groundwater table. The phenomenon of vertical infiltration of saltwater into an aquifer is a density-driven instability problem and is governed by the dynamical interaction of the denser, saline water with the fresh surrounding groundwater. For the numerical solution of the problem we have employed the SUTRA model, using a conceptual model that includes seasonal changes of the groundwater level, tidal variations of the canal stage, rainfall recharge, and a low permeability layer which mimics the canal bed. As expected, whether salt water from the brackish water canal intrudes into the aquifer, depends on the adjacent groundwater table elevation: Lowering the latter during a dry season may initiate the seepage process which then becomes essentially irreversible. A significant influence of the short-term tidal fluctuations on the long-term dispersion of the vertical saltwater plume in the aquifer is found. We have applied the model to simulate how the large Hollywood well field affects salt water intrusion from the adjacent C-10 tidal canal and to determine if and what kind of water management strategies can prevent further intrusion. The models show that for attaining this objective, a minimum threshold water level must be maintained in the well field during the dry seasons. However, because of the huge quantities of water needed, raising the water table cannot be achieved by artificial injection of fresh water, but may be accomplished instead by placing a fresh water canal along the brackish water canal.

EXCHANGE BETWEEN CHANNEL FLOW AND THE HYPORHEIC ZONE

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The hydraulic and biochemical exchange in the river bed between channel flow and groundwater can be found in an intermediate layer called the Hypoheic Zone. To describe the dimensions and processes it is necessary first to know the coherence between hydraulic mechanics, biological activities and chemical processes. These factors are depentent on a time scale, since climate and hydrological variation over the year alter the system. Another aspect in this context is the impact of sewage water in the river system.

Several probes which remove water in a section of the medium scaled River Lahn (Germany) enable the study of the spatial and temporal dynamics of the Hyporheic Zone. All probes are distributed over a length of a few hundreds meters over two large gravel bars and with a sewage outlet half way in between. They are 50 to 100 cm in the river sediment and enable to be taken out water at eight different levels, whereas a pipe-system records all tests simultaneously. The tests are to be used to analyse physical parameters, microbiological actvity and chemical concentrations. Tracer was injected upstream to show the hydraulic exchange at the same time. These subsurface experiments with other hydrogeological investigations like observations in groundwater wells are planned for the seasons next year. The first results of the new installed test field from this year already show the coherence of hydraulic, biological and chemical dynamics.

ASSESSMENT OF THE RECHARGE SYSTEM IN THE FLOODPLAIN OF THE DANUBE (SZIGETKÖZ REGION)

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The role of the main channel of river Danube in recharge and formation of groundwater levels in Szigetköz region was partly replaced by the side arm system operated as an artificial recharge system after the implementation of Cunovo dam. A set of 70 observation wells in 11 groups were established along the side arms in order to collect new information on the efficiency and the qualitative impact of the recharge system. These groups of observation wells contain piezometres at different distances from river channels and at different depths. Considerable differences have been observed between surface water level and groundwater level observed in the immediate surrounding of channels. Two dimensional numeric model has been applied for the estimation of the anisotropy and the river bed resistance by comparing the measured and calculated piezometric levels and for the determination of the flux of recharge as well. The results of the water quality measurements indicate that water quality changes of reductive character took place in the major part of the wells. The prevailing reducing conditions resulted in high dissolved iron and manganese concentrations and in decreased nitrate and increased ammonium content in some wells.

DELIMITING PARTS OF RIVERBED PRONE TO CLOGGING BY ANALYSING BED MATERIAL SAMPLES

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It is known that the yield of bank-filtered wells might significantly decrease due to clogging of parts of the stream channel. In case of coarse bed material, the grains of suspended sediment can penetrate into the pores, clogging them partially or totally. The process is enhanced by the suction effect of the nearby wells. The described physical clogging promotes also the biological and chemical clogging, especially in case of armoured gravel beds, i.e. those parts of the channel which is stable for long periods of time. On the other hand within the stripes of bed-load movement, the grains in the upper bed layer are continuously interchanged, thus no colmatation can occur during transport. During medium floods the width of the armoured part may change or may temporarily disappear during extreme high flood waves. Experience tells that if the armoured bed layer is destroyed, it re-establishes rapidly again practically on the previous location. Grain-size distribution curves of samples taken from the mobile and immobile parts of the cross-sections have been analysed in Hungary for a long time in order to determine their lateral extension. By comparing the results of sampling programs purposely repeated under different hydrological conditions (i.e. long-lasting low-flow periods, floods, etc.) in the same cross-section, the significant changes of the river bed dynamics can be closely followed. These information might be very interesting and useful for the operators of various bank-filtered wells.

field measurements of clogging processes in a river bed

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In river systems the phenomenon commonly referred to as clogging is caused by setting and straining of suspended sediment as water moves through the river bed material. The impoundment of the Danube river in the Vienna region has caused a permanent groundwater flow from the Danube through an artificial island (called Donauinsel) to the New Danube in March 1996. We are investigating the temporal variability of the hydraulic conductivity in the top layer of the river bed at a cross-section 10,4 km upstream from the dam. Piezometer heads are recorded at six points to identify the groundwater flow patterns below the river bed. Due to well defined hydraulic conditions the hydraulic conductivity can be determined with an analytical model. This procedure will be discussed in detail in the oral presentation. In addition, the major independent parameters describing the sedimentary clogging process (i.e., suspended sediment concentration, size distribution of river bed material, hydraulic gradient, flow velocity and the kinematic viscosity) are measured. Significant features from studies of channel bed clogging under laboratory conditions can be evaluated with these measurements. First results of this investigation show the existence of a „quasi-stable" final state of the river bed clogging process and also the effect of flood events on the hydraulic conductivity of the top layer.

HS18/NP1.2 Scaling, fractals and nonlinearity in hydrology

Convener: Onof, C.
Co-Conveners: Olsson, J.; Over, T.M.; Veneziano, D.

GEOSTATISTICAL CHARACTERIZATION OF RANDOM CASCADE FIELDS APPLIED TO THE SAMPLING OF RAINFIELDS

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The first point considered in this study is a geostatistical characterization of cascade random fields. It is pointed out experimentally on generated cascade fields and theoretically that the variogram of cascade fields presents a nugget effect which is independant of the cascade generator model. This nugget effect is function of the branching number and the parameters of the generator model. In the case of a b-model, the nugget effect can be used as a new method to estimate b. The b-estimate given by this method is compared to that produced by other approaches. The second point considered is the sampling problem for the estimation of random cascade field parameters. Given a generator model, cascade fields are generated for different values of parameters by considering different levels of sampling for the calculation of the high frequency component of the cascade field. From the simulated fields the cascade parameters are estimated. The deviation between the cascade fields sampled at various frequencies and the original field is analysed and the nature of this deviation is used to estimate approximately the cascade parameters in for low-frequency sampled fields such as those produced by raingage networks.

Fractal Ordering of Hydrodynamical Patterns

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This paper deals with fractal ordering of different hydrodynamical laboratorial patterns. Instead of solving the governing partial differential equations for the generally hydrodynamical case, statistical analysis of the laboratorial pictures can be an alternative solution of determining different hydrodynamical parameters. In possession of laboratorial pictures with fractal characteristics different statistical function can be elaborated i.e. calculating the block-dimension of a part of the picture. We will show our results is the fractal ordering method, based on the block-counting dimension. Originally a picture is stored by quadtree structure and coded by appropriate ordering system. This method can be based on fractal geometry: the space-filling curves. The problem of using the space filling curves in our case is that for the different pictures the encoding method can not be the same. That is way we try to use in our analyzing system the fractal encoding method with the same block-counting dimension as determined by the laboratorial experiment. A problem is occured when one uses the inverse algorithm (from a block-counting dimension to a fractal shape) because this is an one to infinity connection. This raises an issue that the convergence of the encoding method may be disturbed. In this paper we show and proof a physical based algorithm to choosing a correct fractal shape for ordering hydrodynamical fractal images.

PREDICTING THE DISTRIBUTION AND GEOMETRY OF FRACTURE APERTURES IN THE CHALK AQUIFER.

John Bloomfield (Hydrogeology Group, British Geological Survey)
John Barker (University College, London)

The high transmissivity of the Chalk is attributed to flow through a preferentially enlarged component of the fracture network, and solution enlarged channels may play an important role in the rapid transport of contaminants. However, little is known of the distribution and geometry of solution enlarged fracture apertures. The present study attempts to constrain the problem by using a phenomenological model to investigate the affects of initial aperture distributions and aperture growth laws on the evolution of aperture geometries. Head and velocity distributions are calculated in an idealized 2-d fracture array and the velocities are substituted into an aperture growth rate law, of the form da/dt = fn (q^n), to calculate new fracture apertures. The procedure is then repeated using the new apertures. Low flow rate exponents and small initial aperture variations lead to relatively homogeneous aperture arrays with strong 'parallel plate' geometries, higher flow rate exponents and larger initial variations lead to heterogeneous aperture distributions with complex geometries and in many cases to single, tortuous, channels. Statistical and spatial correlation analyses and multifractal methods can be used to characterise the aperture distributions.

MULTIFRACTAL STUDY OF THE THREE DIMENSIONAL SPATIAL DISTRIBUTIONS OF RAIN AND SNOW IN 10 M^3

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Empirical observation of rain reveals multiscaling behaviour over considerable ranges of scale. This is in contrast to the standard homogeneity assumptions used for modeling drop growth or aggregation or the interpretation of radar reflectivities from rain or snow. High space/time resolution radar rain data reveal multiscaling behaviour down to the resolution scale of a radar pulse volume and theory shows how this can be interpreted in a multifractal framework. If this behaviour continues at sub-pulse volume scales, it will lead to large systematic biases in radar estimates of rain. However, radar resolution scales prohibit the direct verification of this sub-resolution behaviour. In order to directly test the hypothesis that the drop field exhibits multiscaling behaviour at small scales, stereo photography is used to detect rain drops or snow flakes in a volume ≈ 10 m^3. Hydrometeors are lighted by two powerful xenon flashes (50 μs, 2000J). Three motorized Hasselblad cameras help provide accurate estimates of their three dimensional position as well as their size. The overall range of scales is close to 10^4 in all directions. Multifractal analyses relating to the field of liquid water content (for rain drops) and equivalent liquid water content (for snowflakes and ice crystals) are performed and the implications for radar measurements of rain are discussed.

FRACTAL INTERPOLATION OF PRECIPITATION FIELDS

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Recent research has indicated that rainfall may exhibit multiscaling characteristics. A realization of multiscaling process can be viewed as a real-valued self-similar or self-affin field. That is the reason why a new type of "surface-fitting" technique, the fractal interpolation method can be useful to approximate precipitation fields based on raingauge measurements. The fractal interpolation method fits fractal function to the experimental data in a new sense. The graph of the fractal interpolation function has to be close to the data in the Hausdorff metric. Moreover, we require the fractal dimension of the graph of the interpolation function to agree with that of the data over certain range of scales. Preliminary information (like the fractal dimension of the graph) can be calculated by multifractal analysis of rainfall fields measured by weather radar. The paper presents the results of a multifractal analysis for the radar rainfall data measured in Hungary, and some preliminary results for the fractal interpolation of precipitation fields. The impact of data on the result of fractal interpolation is also investigated.

MULTISCALING PARAMETER ESTIMATION FROM RAIN MEASUREMENTS

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Abstract

The uncertainty of multiscaling parameter estimates due to finite sample size is addressed as well as the effects of noise and instrument artifacts on the quality of scaling and accuracy of parameter estimation. Using self-similar cascade simulations we investigate the degree of uncertainty in parameters such as the Fourier spectrum scaling exponent, β, and the codimension of the mean, C_1. Uncertainty in these parameters is discussed in relation to the amount of data available and the length of the scaling range. Simulations of noise and specific instrument artifacts are carried out to investigate the effects of noise and artifacts on scaling and parameter estimates. Noise and other artifacts may introduce scaling breaks and may bias parameter estimates. Specific examples of noise and artifacts include the tipping bucket effect in rain gauges and weather radar noise and artifacts. The tipping bucket effect has pronounced effects at low rainfall rates and thus corrupts analyses of moment scaling especially for low-order moments (q<1).

.TIFRACTAL ANALYSIS AND FORECAST OF SPACE-TIME NFALL FIELDS

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he use of space-time multifractals in order to describe the dynamics of rainfall een proposed by Marsan et al. (Journal of Geophysical Research, 1996), and spond to a mere generalization of anisotropic multifractals to causal multifractal isses. This proposal is tested on rainfall estimates from radar reflectivity data; al problems arise, implying new techniques of multifractal analysis: Eulerian iption of an Lagrangian mutlifractal process, estimation of the scaling stropy between space and time...
Moreover, we exploite the multiscaling properties so to predict the future state of cess known up to a given time; an original method, based only on these iscaling properties, is thus proposed and tested.

SPATIAL RAINFALL DISAGGREGATION FOR LARGE SCALE HYDROLOGICAL MODELLING

Christian Onof, Neil Mackay, Richard Chandler (Imperial College, London SW7 2BU)

A disaggregation model which preserves important spatial features of the rainfall fields is required to enable hydrologists to work at large grid-scales with corresponding rainfall information. The proposed method considers separately the reproduction of the wet areas and the simulation of rainfall intensities. For the first task, a Nearest Neighbour Markov scheme based upon a Bayesian technique used in Image Processing is implemented in such a way that the disaggregation uses the precipitation field at the previous time-step as prior information. Essentially, the large scale field is used as an initial value in an iterative procedure which uses the posterior probabilities of the field. The second task is dealt with by seeking to reproduce both the morphological characteristics of the rainfall field and the distribution of rainfall intensity at a single point. The gamma distribution with a parameter dependent upon the large-scale rainfall is used and the sampled rainfall intensities are assigned to grid-squares according to the distance to the edge of the field.
The scheme is implemented for two different sets of radar data: Arkansas in the USA and Wardon Hill in the UK and the reproduction of some of the spatio-temporal features of precipitation is examined.

THE FILTRATION PROBLEMS SOLUTION USING FRACTIONAL DERIVATIVE TECHNIQUES.

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It is known that the classical filtration equations application are not always suitable for the description non-steady-state hydrodynamic flows in working strata. The consideration of liquids and gases filtration through saturated porous and crack-porous rocks as of casual process in fractal environments results in an idea to use the fractional calculus procedures for the solving the hydrodynamic problems. The author received the filtration equation in fractional derivatives and its solutions for problems of pressure restorations, debit falling, pressure periodic changes in oil wells. The interconnection between fractal dimension and fractional degree in the differential equations is discussed. The comparison of received solutions with experimental data and traditional filtration equations allow to make a conclusion that the fractional differential equations may be applied to solve the filtration problems and for explanation of some nonlinear effects in hydrology.

UNDERSTANDING RAINFALL DETERMINISTICALLY?

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Usage of a deterministic fractal-multifractal, FM, approach to model high resolu tion rainfall time series is reviewed. It is shown that the FM methodology preserves the intrinsic shape and variabilit y present in real rainfall records, allowing to interpret them as projections of f fractal functions. Results for an 8-hr storm gathered in Boston every 15 seconds on October 25, 198 0 and two 12-hr events measured in Iowa City every 5 seconds on November 1 and N ovember 30, 1990 are given. It is illustrated that the FM approach provides very faithful descriptions of bo th major trends and small (noisy) fluctuations for these storms, resulting in pr eservation of not only classical statistical characteristics of the records, but also multifrac tal, and chaotic properties (when) present in them.
These results suggest that a stochastic framework for rainfall may be bypassed i n favor of a deterministic representation based on the concept of projection. Pertinent sensitivity analysis results, extensions and forecasting implications are presented.

PREDICTING GROUNDWATER POLLUTION VIA A DETERMINISTIC MODEL OF PLUME GEOME TRY

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A parsimonious geometric procedure for the description of two-dimensional contam inant plumes, as projections off fractal functions whose graphs lie in three-dim ensional space, is reviewed. It is shown that successful usage of the ideas, to represent successive spatial chloride concentrations as gathered during the Borden site experiment in 1982, y ields a new approach to plume dynamics based on the evolution of surrogate geome tric parameters. It is illustrated that those geometric parameters, some of which are related to dispersion coefficients, exhibit simple trends (in time) which allow predicting the movement of the plume.
Plausible predictions, computed by finding alternative fits to the observed tren ds, are given. It is shown that such predictions: (a) preserve the non-Gaussian and elongated n ature of the chloride patterns, and (b) have covariance tensors which closely ag ree with those implied by stochastic (Gaussian) transport theories (Dagan, 1984) . A generalization of the geometric procedure, to model three-dimensional groundwa ter pollution plumes, is provided.

MULTIFRACTAL ANALYSIS AND DOWNSCALING IN HYDROLOGICAL TIME SERIES

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The multifractal characteristics of two different scaling regimes found in the spectrum of the Belgium rain rates times series are investigated. We first estimate the multifractal exponents associated to the high (between 10 min. and 15 days) and the low-frequency regimes (larger than 15 days). This last regime which possesses a nearly flat spectrum can be viewed as a "multifractal noise" acting at large scales. Under this assumption, we analyze the possibility to generate a multifractal cascade conditionally dependent on the large scale noise. We furthermore validate this approach through a carefull comparison with the statistical properties of the original data.

SCALING LAWS OF FLUVIAL TOPOGRAPHY FROM SELF-SIMILARITY

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In a companion paper (Veneziano *et al.*, EGS 1997), we have shown that, in self-similar (ss) fluvial topography, elevation $h(x,y,t)$ should satisfy $\{h(x_1,y_1,t) - h(x_2,y_2,t)\}|_A \overset{d}{=} r^H \{h(rx_1,ry_1,t) - h(rx_2,ry_2,t)\}|_{r^2A}$ where (x,y) are coordinates relative to the main stream source and $|_A$ refers to a sub-basin of area A with outlet on the main stream. We also found that, under rather general conditions, physically-based dynamic models produce ss topographies with $H = 0$. Here we use self-similarity to derive and extend geomorphological scaling laws of hydrologic interest. We find that several existing laws should be modified, as they have been derived using inappropriate measuring techniques. For example, when flow distance is measured using a ruler whose length varies as $A^{0.5}$, then Hack's Law exponent α and the exponent γ of the contributing area distribution should both be 0.5. We argue that this is the correct way to measure flow distance in ss topographies. For the case when the ruler has constant length, which is the usual practice, we obtain $\alpha \geq 0.5$ and $\gamma = 1 - \alpha$, which are consistent with usually reported values. Based on self-similarity, we reformulate Tokunaga's cyclicity concept for drainage networks, in a way that includes both geometric and topologic features. Our definition relies on drainage area rather than stream orders which are undefined in ss topography. We also show that many natural river profiles are consistent with h being ss with $H = 0$, as predicted by theory. In the past, different conclusions were reached on the self-similarity of such profiles, based on ss conditions other than the one above. Finally, we show in which sense river courses are ss.

BIOSPHERIC ASPECTS OF THE HYDROLOGICAL CYCLE (BAHC)

BAHC01 Interactions and feedbacks between the atmosphere and the terrestrial biosphere

Convener: Claussen, M.

COUPLING OF LONG RANGE TRANSPORTED AIR POLLUTION TO THE SOIL-PLANT SYSTEM: A TOOL FOR IMPACT MODELLING

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A model system is developed providing a process-based dynamic model to couple mesoscale air pollution to vegetation, thereby linking emissions to impacts. The used long-range-transport model is the Danish Eulerian Model, DEM. The model is an Eulerian air pollution model describing emission, long-range transport, dispersion, non-linear chemistry and deposition for a space domain covering the whole of Europe. The biosphere model is a dynamic effect model examining the mechanisms by which plants regulate their carbon, water and nutrient cycles to mitigate damage caused by pollutants such as ozone and acid rain. The aim is to determine the consequences of actual levels as well as projected levels of air pollution by running scenarios over several years in order to evaluate the relative impact of different stress factors (human-made and natural) on vegetation and to develop a tool for evaluation of the effects of different air pollution scenarios on receptors.

A Prognostic phenology scheme for global vegetation models

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Previous sensitivity studies emphasize the role of biosphere feedback on scenarios of global climate change. Models of the biosphere that are coupled to atmospheric general circulation models include many simplifications. One of them regards plant phenology which is either prescribed diagnostically from satellite data or computed using oversimplified relationships. Results from the sensitivity of the simulated present day climate to the prescription of leaf area index (LAI) are presented first. We then discuss predictions carried out using a prognostic model of LAI that is under development in our laboratory. We have focused on the prediction of the onset of vegetation growth. Several models of phenology were calibrated and validated against bud-burst dates retrieved from satellite NDVI data. We have selected for each vegetation type the more reliable model. Predictions are encouraging for temperate biomes, their accuracy being of the same order than the NDVI data one. In the tropics, however, results are less accurate because of unrealistic simulation of precipitation and soil moisture. Finally, we discuss the sensitivity of these models to interannual climate variability.

TRANSPIRATION - THE RELEVANT ATMOSPHERE-SURFACE INTERRACTION PROCESS

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Two different versions of the prognostic surface flux model (acronym PROGSURF) are studied. In PROGSURF, developed jointly at the Universities of Budapest and Vienna, the transpiration parameterization is based on the canopy surface resistance concept. The two versions are tested and compared for humid climate in stand alone mode, using Cabauw data sets. The two versions differ only in the parameterization of the transpiration. In the simple version of PROGSURF, the relative stomatal conductance for expressing water stress effect (RSC_w) is very simply estimated via soil moisture contents taking into account only soil moisture availability effect. In the complex version, RSC_w is parameterized in a very complex way via estimating soil and leaf water potentials considering not only soil moisture but also the atmospheric effect. The output of the two model versions is analysed and compared. As expected, the complex version gives more realistic results than the simple one. For example, the annual Bowen ratio is 0.145 (too big) in the simple version and 0.055 (about correct) in the complex version. In the coupled mode (not described here) PROGSURF generates the boundary conditions for an atmospheric model.

NEW REPRESENTATIONS OF VEGETATION PHYSIOLOGY AND SOIL THERMODYNAMICS IN THE HADLEY CENTRE GCM

Richard Betts (Hadley Centre for Climate Prediction and Research, UK Meteorological Office, Bracknell, Berkshire, UK, RG12 2SY)

Recent modifications to the Hadley Centre General Circulation Model (GCM) include a revised formulation of land surface processes, the Met. Office Surface Exchange Scheme (MOSES). The first version of MOSES features a photosynthesis and canopy conductance model, and a new soil thermodynamics scheme. The photosynthesis model simulates primary productivity and allows stomatal conductance to vary in response to near-surface meteorology and atmospheric CO_2 concentration; this has a direct effect on the rate of transpiration. The new soil thermodynamics allows soil moisture to freeze and thaw, and the corresponding release and uptake of latent heat modifies the evolution of surface temperature. Clearly, both the interactive conductance and the soil moisture phase change have the potential for significant impacts on the simulation of contemporary climate. Furthermore, they may also be expected to influence the climatic sensitivity of the GCM to an increase in greenhouse gas concentrations, by providing new feedbacks in response to both temperature and CO_2. This paper examines the impact of MOSES on the GCM, and assesses its potential importance in forthcoming predictions of climate change.

ANALYTICAL STUDY OF CLIMATE-VEGETATION INTERACTION: CONTINUOUS MEDIUM APPROACH

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Terrestrial vegetation model based on a fractional land cover description, namely VECODE (VEgetation COntinuous DEscription) model, was developed. In the model, the land is covered by a mixture of trees and grass (plus a desert, as a dummy type). In order to use the analytical approach, the description of climate system was extremely simplified. The impact of desert/snow fraction on albedo is the background of local dependencies of climate parameters on vegetation fractions.
Two areas are of interest for our study: northern tundra and subtropical desert. Shifts of vegetation zones in these areas may lead to regional or even global climate change. The analysed system of locally interacting climate and vegetation demonstrates interesting dynamic behaviour, including bifurcation and multistable equilibria.

PHYSICAL PROPERTIES OF AMAZONIAN SOILS - A MODELING STUDY USING THE ABRACOS DATA

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The hydraulic properties of some Amazonian soils differ significantly from the properties of the temperate soils. Most of the soil water release functions implemented in the atmospheric models used in deforestation studies were developped for temperate soils. It is necessary to check the validity of these soil water models with in-situ data. In this study, the ABRACOS soil data have been used to modify the parameter values of Clapp and Hornberger's water release model. Different relations between hydraulic parameters and texture are drawn. These relations are included in the ISBA land-surface scheme which is used to simulate the long term evolution of the soil water content and the surface energy balance of three contrasting ABRACOS sites: two pasture sites with distinct soil properties and a forest site. The sensitivity of the simulations to the use of either the original Clapp and Hornberger water release model or the ABRACOS derived one is shown.

INTERACTIONS BETWEEN A FULLY DYNAMIC LAND SURFACE AND A GENERAL CIRCULATION MODEL

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We present results of off-line simulations using the dynamic vegetation model Hybrid v 4.0, developed at the Institute of Terrestrial Ecology (ITE), Edinburgh and the General Circulation Model CCM3 developed at the National Center for Atmospheric Research, (NCAR), Colorado. The latter uses a land surface model (LSM, Bonan 1996) which operates with a time-invariant vegetative surface. Hybrid, on the other hand, is a process-based ecosystem model, driven by climate and atmospheric CO_2 concentration, which predicts transient changes in vegetation. Simulations have been performed by running CCM3 to equilibrium and using these model results as the climate input to Hybrid, which is in turn run to equilibrium. Predictions from Hybrid have then been used to update the LSM vegetation surface dataset. This procedure has been repeated until the two models reach mutual equilibria. By exchanging information between the two models in this manner, it is possible to quantitatively examine climate-vegetation feedbacks.

A STUDY OF BIO-GEOPHYSICAL FEEDBACKS WITH A COUPLED CLIMATE-BIOSPHERE MODEL CLIMBER-2

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The quantitative analysis of the strength of bio-geophysical feedbacks (BGFs) were investigated using a coupled climate-biosphere model CLIMBER-2. CLIMBER-2 is a low resolution seasonal model of the atmosphere, ocean (including sea ice and oceanic carbon cycle), land and terrestrial vegetation interacting through the fluxes of energy, momentum, water and carbon. The model is designed for long -term integration and shows good performance in simulation of the present state of the Earth system and its sensitivity. The strength of BGFs expressed in term of *amplification factor* was calculated for variations of different climate forcing parameters: CO2 concentration, solar insolation, orbital parameters. The most sensitive regions ("*hot spots*") and the most important processes for BGFs were defined and analysed. It is shown that BGFs could substantially affect climate sensitivity. The role of BGFs for stability of the Earth system to external and internal perturbations is discussed.

IS FOREST ALBEDO MEASURED CORRECTLY?

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The forest albedo is an important meteorological and ecological variable characterising the forest ecosystem. In order to measure this variable two 2π-sensors are mounted above the forest canopy. The first one records an upward radiant energy flux from the forest canopy into the atmosphere, and the second - a downward radiant energy flux from the atmosphere into the forest canopy. The ratio of their responses is usually interpreted as the forest albedo. This measurement method is included in standard observation programs at many research stations. In the present paper we quantify an inadequacy of this method to evaluate the forest albedo for photosynthetically active region (PAR, 400-700 nm) of the solar spectrum. We reproduced the three-dimensional PAR radiative field above a coniferous forest stand at the scientific research station „Solling" near Göttingen with high level of realism so that a good agreement between a simulated sensor response to the simulated radiative field and a real sensor response to the real radiative field was achieved. The forest albedo derived from the simulation results was found to be underestimated by the sensor on a clear sunny day by about a factor of 3 during morning and evening hours and by about a factor of 1.9 during day time. This deviation is mainly caused by forest heterogeneity. A daily mean of the measured solar radiant energy fluxes the ratio of which is usually assumed to represent the albedo does not average the effect of the forest heterogeneity.

AN ADVANCED MODEL FOR THE SCATTERING OF LIGHT BY VEGETATION IN THE SOLAR DOMAIN: THEORY AND APPLICATION

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The terrestrial biosphere, a major component controlling the hydrological cycle, can be characterized and monitored at the regional and global scales using remote sensing data from space. The proper interpretation of such measurements relies on the availability of radiation transfer models to accurately describe the complex interaction between electromagnetic radiation and the biogeophysical properties of the terrestrial surfaces. To this end, we propose an advanced bidirectional reflectance factor model which constitutes the latest advance in representing the transfer of radiation in a homogeneous plant canopy, capitalizing on the progress achieved over the last ten years, in particular the discrete representation of a plant canopy (as opposed to a purely turbid medium) for the first orders of scattering as well as an accurate description of the multiple scattering processes for an optically finite medium. The results of simulations obtained with this model compare quite favorably with those produced using a ray-tracing model and a number of examples of such comparisons will be shown for a wide range of vegetation conditions. This model has been used in inverse mode against global AVHRR data sets, to estimate values of parameters characterizing the terrestrial surfaces such as to the Leaf Area Index.

COUPLING OF AN ATMOSPHERIC BOUNDARY LAYER MODEL WITH A SINGLE-LEAF GAS EXCHANGE MODEL

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Interactions and feedbacks between the vegetation and the atmosphere depend especially on local conditions of radiation and turbulent exchange as well as on vertical and horizontal extension and texture of the canopy. To study these mechanisms, a first model version to describe coupling between atmospheric boundary layer and leaf gas exchange (model PSN6) had been developed (HIRVAC - HIgh Resolution Vegetation Atmosphere Coupler). HIRVAC has 120 numerical levels, about 60 in a canopy like forest canopies with a tree height of 30m. Vertical extension and texture of vegetation can be adjusted. Coupling between atmosphere and vegetation is realized by stomatal and aerodynamic conductance gs and ga, which are calculated in the PSN6 by using the well established mechanistic Farquhar-model of C3-gas exchange combined with the empirical formulation for gs according to Ball. In HIRVAC vegetation is represented as horizontal layers of homogenous LAI and radiation interception is calculated according to Beer's law. PSN6 is integrated in each model layer in the canopy and at each time step there is a data exchange between the atmospheric and biological part of HIRVAC. Model experiments show the influence of physiological parameters, canopy height, density of the canopy and influence of radiation on the turbulent regime in and above the vegetation cover. For example the effect of drying up and drying stress on a pine forest stand could be simulated.

BIOGEOPHYSICAL FEEDBACKS AND THE AFRICAN MONSOON AT 6ka

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Large changes in the extent of northern subtropical deserts during the Holocene are attributed to orbitally-forced variations in monsoon strength. Models that omit biogeophysical feedbacks cannot account for the full magnitude of African monsoon amplification and extension during the mid-Holocene. The incorporation of feedbacks related to vegetation changes amplifies the orbitally-induced change in the African monsoon, but not by enough. A new data set of land-surface conditions at 6ka across northern Africa and the Arabian peninsula has provided realistic lower boundary conditions for a series of 6ka AGCM experiments The simulations show the climatic effects of sequentially incorporating feedbacks due to observed changes in vegetation, soil type, the extent of wetlands and of lakes. The consequences of these climatic changes for vegetation distribution are assessed using a biome model and the realism of the simulations is measured by comparisons with independent palaeoenvironmental data sets.

INFLUENCE OF THE VEGETATION ON THE ATMOSPHERE AT A MICROMETEOROLOGICAL LEVEL

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We analyze the influence produced by different objects (shrub and grass) on the atmosphere at a micrometeorological level. The results permit to assert that the vegetation modifies its environment in such a way that originate vertical and horizontal thermal gradients. These gradients and the lags in response to the warming and as to the cooling are enough to cause energy and matter transfers through the frontier. The atmosphere generates convective processes that tend to decrease these gradients. The phenomena that we have described could reverse in the vegetation motivating the advance or regression of the frontiers upon favoring to some species in respect to other in a several years lapse.

BIOGEOPHYSICAL FEEDBACK DURING THE LAST GLACIAL MAXIMUM

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An asynchronously coupled global atmosphere-biome model is used to assess the stability of the atmosphere-vegetation system under climate conditions (solar irradiation, sea-surface temperatures, sea level, inland ice, CO_2) valid for the Last Glacial Maximum (LGM) some 21000 years before present. It is found that the coupled model on average yields a better agreement with paleo-geological reconstructions than an atmosphere-only model.
Sensitivity experiments reveal the following: When initialized with different land-surface conditions the atmosphere-biome model finds two equilibrium solutions: the first solution yields a (presumably) realistic wide spread distribution of subtropical deserts, the second reveals a moister climate in North Africa and Central East Asia and thereby a northward shift of vegetation particularly in the south-west Sahara.

FOREST GROWTH RESPONSE TO CHANGING CLIMATE BETWEEN 1981 - 1990 IN AUSTRIA

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Changes in climate as well as increased increment rates have been reported for European forests. The purpose of our study is to explore if climate change could have caused this increase in forest growth. Using 30 years of climate records from 20 weather stations including daily minimum and maximum temperature and precipitation, we investigated the magnitudes of temperature changes and the change in the length of the growing season between 1981-1990 and 1961-1990. The growing season is defined as the sum of days with an average daily temperature of greater than zero. Finally, we used the biogeochemical model FOREST-BGC to predict the annual NPP production since 1961. The results of the study indicate: (1) no change in precipitation; (2) an average temperature increase between 1981-1990 of 0.7 degrees Celsius vs. 0.8 between 1961- 1990; (3) increasing length of the growing season of 20 days (1981-1990); (4) increase in total NPP production by 12 % in the eighties vs. only 2 % between 1961-1990; (5) relatively higher increase in the number of growing days and NPP in mountainous terrain vs. lower elevations; These trends are consistent with the findings by the Austrian National Forest Inventory of 5000 permanent plots which reports 20 % higher increment rates in the 1980s.

INFERRING ROOTING DEPTH FROM A TERRESTRIAL BIOSPHERE MODEL AND ITS IMPACTS ON THE SIMULATED CLIMATE OF THE ECHAM4 GCM

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Deep roots are common in some tropical ecosystems and are necessary to provide sufficient soil water storage to maintain green canopies during the dry season. In contrast to this, land surface schemes of atmospheric General Circulation Models and global models of the terrestrial biosphere generally assume rooting depths to be less than 2 m. How common are deep roots on the global scale and is it important to include the effects of deep roots in global models? We present a method of how to derive a global distribution of rooting depth from a terrestrial biosphere model by maximising its annual Net Primary Production in respect to rooting depth. This data set is then used for a simulation run of the ECHAM GCM. The results show, that an increased rooting depth significantly alters surface climate in some tropical regions. Due to the enhanced latent heat flux into the atmosphere, regional hydrology is changed and feedback processes to the atmospheric circulation are produced. We verify modified hydrology by using river basin drainage and conclude, that it is necessary to include the effects of deep roots in tropical regions of global models.

CARBON BUDGET IN TROPICAL RAIN FOREST 6000 YEARS AGO AND THE HYDROLOGIC EQUILIBRIUM CONSTRAINT.

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Bioclimatic schemes developed to assess the impact of possible human induced CO2 and climatic changes, can be tested through a comparison of their results with paleoinformations (pollens andice record of atmospheric CO2).
The mid-Holocene period (6000 years ago) presented a higher insolation in the northern hemisphere, enhancing thus the temperature gradient between northern continents and ocean which level and surface temperature were similar to present. This phenomenon is believed to have modified intertropical past monsoon events and associated precipitations.
Due to their high carbon content in soil and vegetation, a contraction or extension of Tropical Rain Forest (TRF) may have strong consequences on the global carbon cycle.
The mid-Holocene climate, calculated with the CCCMA GCM is coupled with an hydrologic equilibrium model based on Leaf Area Index adjustment. This approach allowed us to assess the migration of the TRF border and the resulting impact on carbon storage.

EXCHANGES BETWEEN STRUCTURED CANOPIES AND THEIR PHYSICAL ENVIRONMENT: A SIMPLE ANALYTICAL SOLUTION FOR A GENERIC CONFIGURATION

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Evaporation and photosynthesis result from complex bidirectional atmosphere-biosphere interactions. More often than not, the Soil-Vegetation-Atmosphere-Transfer (SVAT) models in general circulation models (GCMs) and the land-surface packages in terrestrial vegetation models treat evaporation and photosynthesis as two independent processes. Representing in a simple and accurate way the opening of stomates, the simultaneous diffusion of carbon dioxide into the leaf and of water out of it presents a number of challenges. The "ESCAPES" (Exchanges between Structured Canopies And their Physical Environment: a simple analytical Solution) framework provides a generic, analytical solution for the exchange of physical or chemical quantities–other than visible and near infrared radiation–between the atmosphere above a structured plant canopy and the canopy itself. As such, among other things, ESCAPES provides a means to meet upfront the challenge set by the bidirectional question of evaporation and photosynthesis integration.

A NEW APPROACH TO MODEL RAINFALL INTERCEPTION AND INTERCEPTION EVAPORATION

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Under humid climate conditions the storage of water on the vegetation and subsequent evaporation of the intercepted water plays an important role in the hydrological cycle. However, knowledge about the related processes is limited and therefore simplified assumptions are frequently used in hydrological models.

Based on field studies of interception in herbaceous and dwarf shrub communities as well as on theoretical considerations a new interception model will be presented. Herein the amount of intercepted water is calculated in relation to the canopy storage capacity, which is a function of the leaf area index. A non-uniform distribution of the intercepted precipitation inside the canopy is assumed. For that purpose the canopy is subdivided into an optional number of layers. In contrast to usual conceptions the intercepted water on the plant surfaces is not considered as a closed film but it forms individual, hemispheric particles. Water remaining on the canopy at the end of a storm evaporates from the individual layers with different intensities. In addition, evaporation of intercepted water can also occur during rain.

Model results for different growing seasons show that interception evaporation contributes more than 20 % to total evapotranspiration. For individual months this value can reach up to 50 %. In addition, calculated wetness durations account up to 80 % for selected months.

ON COUPLING ATMOSPHERIC GENERAL CIRCULATION MODELS TO GLOBAL BIOME MODELS

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Sensitivity experiments using atmospheric general circulation models (AGCMs) have demonstrated the importance of biosphere/atmosphere interactions for climate studies. In addition there is evidence, from paleoecological data, that the global distribution of biomes has strongly varied through time. Therefore a full treatment of climate change, past or future, requires the use of biosphere models that are able to compute a redistribution of biomes.

Coupled AGCM-Biome models have been developed since 1993. "Static" biome models were used, requiring as input an "equilibrium" state of the atmosphere. Such a coupled model was applied to simulations of present-day climate, to test whether the AGCM was in equilibrium with the prescribed present-day land-surface conditions. Applications were also carried out for past climates. It has been shown for example that accounting for feedbacks from vegetation redistribution during the start of the last glacial period may have contributed to the build up of continental ice-sheets.

We will show results from coupled simulations of both present and past climates. We will discuss a recent comparison of two coupled simulations of the mid-Holocene climate, using the same biome model but different AGCMs. One of them is able to develop grassland and shrub vegetation in large parts of the Sahara, while the other is not. Is this discrepancy mainly due to the use of a different coupling strategy, or to different land-surface parametrizations within the AGCMs?

TURBULENT EXCHANGE OF CARBON DIOXIDE AND WATER VAPOUR BETWEEN THE ATMOSPHERE AND A HIGH ARCTIC WET TUNDRA

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Turbulent fluxes of carbon dioxide and water vapour were measured continuously for two months by eddy correlation over a wet meadow tundra system at Zackenberg (74°28'12''N,20°34'23''W) in NE-Greenland 1996. The measurements started just after snow melt in June and continued until the end of the growing season in the middle of August where the active layer had reached a depth of 0.6m. The meadow vegetation the fluxes represent, consist roughly of very wet *Eriophorum scheuchzeri*/*Carex atrofusca* meadow tundra with water levels at or just beneath the surface and of patches of moderate wet *Salix arctica*/moss tundra. Downward fluxes of carbon dioxide increased over the period from near zero flux in the beginning to about 0.4 $mgm^{-2}s^{-1}$ on sunny days in the later part of the growing season. Maximum water vapour fluxes were measured to about 150 Wm^{-2}. Both fluxes displayed a clear diurnal variation the whole period primary controlled by incident solar radiation. In the case of carbon dioxide the general trend was that the downward fluxes caused by photosynthesis far exceeded the respiratory fluxes showing that this meadow tundra system was acting as a sink of carbon dioxide.

MODELING OF TWO-DIMENSIONAL DYNAMIC-THERMAL FLOWS IN AND OUTSIDE FOREST CANOPY

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A numerical model is built for investigating the dynamic and thermal influences of forest canopy on u-w wind field and the distributions of air temperature and turbulent kinetic energy(TKE). Primary control equations are used with "shallow convective" and "quasi-geostrophic" approximations. Turbulent transportation in both horizontal and vertical directions are parameterized by the "K-theory". Gusting effect is formulated as a gradient of vertical stresses and introduced into the control equations. The simulated domain is 600m width and 150m height within which the two-dimensional forestry is 300m length and 12m height. Long and short waves radiation is involved as a basic physical process for thermal exchanges between canopy and atmosphere. "Arakawa-E" grid-point set is designed by the finest resolution (2m×0.5m) within canopy and the roughest one (8m×10m) far away from canopy. The total number of grid points is 231(horizontal) × 47(vertical) and the time step is one second. A nearly neutral case is chosen from the field measurement in New Mexico during the summer of 1996 as an initial and steady boundary condition. The steady state of u-w field is simulated by running the model under the left steady boundary forcing. The result shows that difference of wind speed profiles from upstream to downstream is mainly resulted from the dynamic effect of forest canopy.

PARTIAL DEFORESTATION OF AMAZONIA; A GCM STUDY.

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The impact of a 50% deforestation in the Amazonian basin is studied with the help of 3 10-year GCM experiments. The LMD-GCM is coupled to the land-surface scheme SECHIBA which was previously calibrated to the ABRACOS data. These experiments correspond to 3 possible patterns: i) a homogeneous deforestation over the entire basin, ii) removing all forest from a random selection of 50% of grid-boxes over the region iii) and the same area in one block to the South East of the basin. The homogeneous distribution is made possible by the mosaic approach the SECHIBA scheme uses to represent the sub-grid scale variability of vegetation. These scenarios are intended to be more realistic representations of possible future deforestation in Amazonia than a complete removal of all the forest.

The comparison of these experiments with a control integration and a total deforestation experiment leads to the discussion of how the regional distribution of the land-surface change affects the climatic impact. It is shown that the homogeneous deforestation, i.e. at a sub-grid scale for the GCM, induces the smallest changes on land-surface fluxes and atmospheric variables. In the wet season all scenarios impact the circulation of South America in similar patterns but to different degrees. However in the dry season and for surface fields the deforestation patterns impose different structures to the changes.

PILPS PHASE 4(b): COMPARISONS of LAND-SURFACE SCHEMES COUPLED IN A REGIONAL NWP MODEL

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PILPS: the Project for Intercomparison of Land-surface Parameterization Schemes is a World Climate Research Programme project. Its goal is to improve the understanding of the parameterization of the interaction between the atmosphere and the continental surface in climate and weather forecast models. In PILPS Phase 4(a), selected schemes are coupled to a common Numerical Weather Prediction (NWP) model: the Limited Area Prediction System (LAPS) developed by the Bureau of Meteorology and Research Centre (Melbourne). An important issue for Phase 4 of PILPS is the similarities and differences allowed among participating land surface schemes and their couplings. Areas to be considered includes: the atmospheric forcings, the surface characteristics, the initialization procedure and the coupling techniques (call, return variables, outputs). The results produced by each scheme in this Phase of PILPS are analysed and compared with the previous performance of these schemes in the off-line experiments of PILPS. The partitioning between surface fluxes is studied as well as the soil moisture budget. Both global and local results are analysed. Finally the quality of the model forecasts are investigated.

FFECT OF FOREST VEGETATION ON THE RADIATIVE REGIME IN IOUNTAIN REGIONS.

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t was shown (Vygodskaya , 1975-1983), that the extinction of solar radiation luxes by the dense forest canopy is stronger that the radiation extinction by the loudness of lower layer, and considerably stronger than the decreasing of radiation lue to northern orientation of steep mountain slopes. On the base of long-term field neasurements, of analysis of thousands of hemispherical photos and of direct adiation measurements at mountain regions of Far East, Siberian, Middle Asia and Caucasus the semi-empirical model was developed. The model allows to calculate he direct and total solar radiation for slopes as a functions of Sun position, of itmospheric turbidity, of cloudness type and amount, os slope orientation and nclination, of horizon closure, of gap fraction in forest stands of various spicies content and phenological phase. Thus the model allows to retreat the daily, seasonal and annual course of radiation sums for certain ecosystems and landscape units of different range. The model didn't take into account the anisotrophy of reflected radiation for calculation of short.wave radiation balance. The new three dimensional model (Knjazikhin et al., 1996) allows to correct the estimation of albedo for afforested mountain slopes. In a whole the model give a possibility to get a rather realistic evaluations of energy recources of slopes covered by forests.

BAHC02 Integrated biosphere atmosphere experiments: boreal and arctic region - northern Eurasia studies

Convener: Schulze, E.D.

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Vegetation/Climate interactions in the Distant Past

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Climate/biogeographic model simulations of the Cretaceous and Jurassic provide an unusual test of for these models. The period is of interest as it appears to be a time of relative warmth and high natural levels of CO_2. We present results from simulations using the UGAMP GCM coupled to the biogeographic model called MAPSS (Mapped Atmosphere-Plant-Soil System). We have performed a number of interations until the UGAMP GCM and MAPSS produce a self consistent prediction of climate and biomes. The resulting predictions of climate and vegetation can be directly compared to the fossil plant record. The results suggest a strong feedback between vegetation and climate during these periods, and which at least in part, helps explain the relative warmth especially at mid and high latitudes.

Carbon dioxide balance at two arctic sites in Northern Europe

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The northern ecosystems are among the key areas when estimating the influences of the changing climate. We report on CO_2 and energy balance measurements made in Finnish Lapland on two different ecosystems during field campaigns in 1995 and 1996. The 1995 campaign was performed over the period 15 August to 13 September on a flark fen at Kaamanen (69°08'N 27°17'E) 150 km south of the Arctic Ocean. The 1996 campaign was carried through over the growing season (20 May-15 September) on a mountain birch forest (69°28'N 27°14'E) 40 km north of the fen site. This study is a part of the EC-funded project Understanding Land Surface Physical Processes in the Arctic (LAPP) which aims at understanding the processes underlying the energy and mass balance for arctic land surfaces through a programme of measurements and modelling.

IMPORTANCE OF LANDSCAPE AGE AND PLANT COMMUNITY COMPOSITION FOR THE SURFACE ENERGY BUDGET AND CARBON FLUXES IN ALASKAN ARCTIC TUNDRA

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It has only recently been recognised that differences in landscape age in low arctic tundra, which has a strong impact on soil pH, soil moisture, and plant species composition, must also lead to important differences in surface energy budget and carbon fluxes. We present direct comparisons of eddy correlation flux measurements from a younger moist nonacidic and an older moist acidic upland tundra site obtained during the 1995 ARCSS LAII Flux Study in the Kuparuk River basin, Alaska. Those two landscape types account for roughly 70% of the study area. We chose our sites close to each other such that they experienced similar climate and surface soil moisture. Ground heat fluxes and carbon fluxes revealed the largest differences among sites, while sensible and latent heat fluxes are similar under average summer weather conditions, but show large differences on sunny days with little or no clouds. The application of a SVAT model (GasFlux) reveals the importance of moss evaporation which accounts for roughly 70% of total latent heat flux at the acidic site. The differences in surface energy fluxes are explained primarily by differences in the moss layer, shading produced by shrubs, and local microtopography (and thus surface soil properties). Differences in carbon fluxes are explained by differences in leaf area index, plant growth form and carbon storage in the organic layer of the soil.

PERIODICAL MEASUREMENT OF GREENHOUSE GASES VERTICAL PROFILES OVER SIBERIA BY AN AIRCRAFT SAMPLING METHOD

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The vertical distributions of CO_2, $^{13}CO_2$, CH_4, N_2O and CO have been observed periodically, once per month, by an aircraft sampling followed by a laboratory analysis over Surgut(61N, 73E), West Siberia, since July, 1993. The air is sampled in a set of glass bottles up to 3 atm. on an chartered airplane, An-24, at eight altitudes from 500 to 7,000m. The concentration of CO_2 at 500m varies between 340ppm in summer and 370ppm in winter, the amplitude is 35, 25 and 25 in '93, '94 and '95, respectively, while the variation at high altitude is about 12ppm. This larger amplitude than that over Japan, between about 8 and 16ppm, is due to a more direct influence of continental biosphere. The seasonal variation of CH_4 at 500m has two peaks both in summer and winter. The peaks in summer is ascribed to the methane emission from natural wetlands, and that in winter is speculated to the leakage from natural gas pipelines combined with the strong temperature inversion and weaker wind in winter which keep CH_4 near surface. This approach is one of the ways to evaluate the greenhouse gas budget of the terrestrial biosphere, and the formation of vertical profile measurement network is desired.

THE ROLE OF WEST-SIBERIAN AND EAST-EUROPEAN RUSSIAN PEAT DEPOSITS IN THE GLOBAL TERRESTRIAL CARBON CYCLE

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The total area occupied by northern peatlands has been estimated at 200-400 million hectares, or 1.3-2.7 % of the total land surface on Earth and 12-25 % of boreal and Arctic regions. Northern peatlands are important in the global terrestrial carbon cycle for a number of reasons: 1) over the Holocene period they have accumulated 180-450 Pg of carbon, i. e. 7-16 % of the total terrestrial carbon pool, 2) undisturbed peatlands continue to accumulate carbon at a rate of 76 Tg/yr, and 3) they release carbon in the form of methane at a rate of 46 Tg/yr, i. e. c. 10 % of the world's methane emissions. A vast area of western Siberia and, to a minor extent, eastern European Russia is covered by peatlands. Recent estimates give for these regions an area of 155 million hectares, a carbon pool of 198 Pg, a carbon accumulation rate of 46 Tg/yr, and a carbon release through methane emissions of 14 Tg/yr. Many uncertainties still beset all these numbers.

Northern taiga and tundra peatlands are underlain by extensive permafrost. Permafrost dynamics affect the topography and hydrology of peatlands, the extent of wet surfaces, and the methane flux to the atmosphere. Additional research is needed to evaluate the total amount of carbon sequestered in west-Siberian and east-European Russian peat deposits, the rate of methane emissions, and the effects of climatic warming and associated permafrost thawing and more frequent peat fires.

Interpretation of eddy correlation measurements of CO_2 and CH_4 from Northern Sweden.

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During early May 1996 eddy correlation measurements of CO_2 and CH_4 were conducted over a mire near Abisko in Northern Sweden. This campaign was followed by brief campaigns in late June and September. Other studies have shown that the dynamics of carbon dioxide and methane exchange is largely affected by water content and temperature of the soil. To evaluate this effect simultaneous measurements of the exchange of these gases were made over wet and dry parts of the mire using the static chamber technique. This presentation shows the diurnal and seasonal variations of these fluxes and a comparison of the results obtained with the two very different methods. Further an interpretation of Landsat satellite images have been conducted to evaluate the possibility for up scaling the fund results to an estimate of the exchange of CO_2 and CH_4 covering the Abisko region.

SEASONAL VARIATION OF CO_2, WATER VAPOUR AND ENERGY EXCHANGES OF A BOREAL BLACK SPRUCE FOREST

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Measurements of the fluxes of latent heat, sensible heat and CO_2 were made by eddy covariance as part of the BOReal Ecosystem Atmosphere Study (BOREAS) from mid-March to end of November 1996 with the particular aim of catching the thaw in the spring and the freeze-up in the fall. Interannual comparison is possible with the 120 days of data through the growing season in 1994. The eddy covariance system comprised a sonic anemometer 27 m above the forest, a system for transferring rapidly and coherently to a closed path, infrared gas analyser and a computer with the Edinburgh *EdiSol* software. As in 1994, 24 hour energy balance closure was good (~ 0.97) and mid-day Bowen ratios were typically in the range 1.2 to 2.5 as previously. There was a small daily loss of carbon throughout the winter. Significant carbon gain began on about 20 April and continued until about 20 October. During this period there was a loss of carbon on c. one-third of the days and significant gain on the other two-thirds. The overall storage of carbon for the year was somewhat less than the carbon storage over the growing period during 1994. As in 1994, the net ecosystem flux was a delicate balance between photosynthesis during the day and losses by autotrophic and heterotrophic respiration during both day and night. High solar irradiance promoted influx of CO_2 by the foliage: high temperatures reduced net CO_2 influx through high respiration rates by the roots and soil micro-organisms.

SEASONAL VARIATION OF CARBON AND WATER FLUXES OF A BOREAL FOREST IN CENTRAL SWEDEN

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Two years, from June 1994 to May 1996, of continuous net ecosystem flux measurements above a boreal forest in central Sweden show that the forest during this period has acted as a source and that it is sensitive to changes in temperature. Although annual mean temperature stayed close to normal these results are mainly explained by higher than normal respiration and low soil moisture during the 1994 season. Even in the middle of the summer, there are many days with positive fluxes, i.e., the forest acts as a source of carbon, and these occasions are correlated with overcast and warm weather. Also noticeable are the consistent positive values during winter. The warm winter of 1994/95 shows rather large positive fluxes but also the cold winter 1995/96, with a mean (November - February) air temperature of -6.0 ° C, shows small but significant positive values. The maximum evaporation is about 4 mm per day and the annual mean is close to 1 mm per day.

SPATIAL ANALYSIS OF CENTRAL SIBERIA VEGETATION BY PROXIMAL SENSING

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During a Central Siberian scientific expedition in summer 1996 spectral images of vegetation canopy have been taken by means of a newly developed proximal sensing system. The system is composed of 4 CCD cameras and an image compressor able to store images on a magnetic tape. The system is light weighted (approx. 2 Kg) and it has been mounted on a helicopter for the campaign flights. Images characteristics are: spectral resolution 10 nm or 50 nm; interferencial pass band filters 400-450 nm, 520-570 nm, 675-685 nm, 775-785; radiometric resolution 8 bit; spatial resolution 30 cm or 1,5 m. In these study, by digital imaging processing (vegetation indexes like SR, NDVI) and by analysis of pictures texture and structure, the spatial composition of Taiga forest and other vegetation types in undisturbed natural areas and managed lands have been analyzed. The data set obtained show a marked enviromental heterogeneity of Central Siberian landscapes caused by frequent fires from small to large spatial scales which determine a rather uneven aged distribution of forests. Considerations are made on biodivesrity and ecological significance of landscape heterogeneity.

Spatio-temporal pattern of soil respiration in an arctic tundra watershed. Minimum requirements for a realistic prediction.

B. Ostendorf (European Academy, Bozen, Domplatz 3, I-39100 Bozen, Italy)

This presentation argues, that scaling up from the leaf level processes to landscape is possible and necessary. In a small Alaskan tundra headwater, carbon balance is studied with the means of a model complex including ecophysiological processes, vegetation classification models, and the prediction of spatio-temporal hydrological processes. The whole system reacts to increased CO_2, temperature and irradiation regime similar to the small scale models. The major difference between leaf level response and landscape scale response is a linearization, suggesting that at large scales simple empirical linear response models may well represent complex system behavior to multivariate influences. Less intuitive is the model response to increased precipitation since spatial patterns of water flow and the feedback of plant transpiration on water table and soil respiration need to be considered. A decrease of precipitation by 40% for example had the same effect as an increase of temperature by 4K on seasonal landscape scale carbon balance. Model and data deficiencies are discussed in order to suggest future field work.

CANOPY MASS AND ENERGY EXCHANGES IN TWO CONTRASTING LAND COVER TYPES IN CENTRAL SIBERIA : FOREST AND BOG

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Eddy fluxes measurements were carried out during a Central Siberia scientific expedition in summer 1996. Continuous flux data on carbon dioxide, water, sensible heat and momentum for almost a complete month in July were collected. The ecosystems under investigation were a young forest under regeneration (about 12 years old) and a bog area.

The energy exchanges at the surface and their partitioning presented a marked difference between the forest and the bog showing a bowen ratio of about 4 and 1, respectively, in the central hours of typical sunny days.

The lower water flux of the forest is paralleled also by a smaller carbon uptake than the bog surface and it is the result of nutrient limitations and the high soil CO2 efflux, measured by chamber techniques.

SEASONAL, LARGE-SCALE ESTIMATION OF TRACE GAS FLUXES IN ARCTIC ALASKA

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The circumpolar arctic has recently shifted from a carbon sink of perhaps 0.1 to 0.2 GtC/y in historic and Holocene periods, to a carbon source of as much as 0.7 GtC/y in response to recent warming and drying. The US National Science Foundation, Arctic System Science Program: Land Air Ice Interactions Flux Program is attempting to determine the spatial extent and seasonal pattern of CO_2 loss and sequestration using a variety of measurement and modeling approaches at plot, landscape, and regional scales CO_2 flux measurements are made using chamber, tower eddy covariance, and aircraft based eddy covariance measurements. These measurements are made diurnally and seasonally. These data are combined with remotely sensed information (e.g. SAR, spectral imagery) and modeled environmental data (vegetation, depth of thaw, soil organic matter, temperature, soil moisture) to calculate seasonal regional carbon fluxes. One goal is to develop the capability to estimate regional circumpolar seasonal carbon fluxes primarily from remotely sensed data, with minimal key ground based measurements. Regional growing season carbon fluxes have been calculated for the Kuparuk basin. Results indicate that the whole 12 month carbon balance for the Kuparuk Basin continues to be a source of CO_2 to the atmosphere. Winter CO_2 losses to the atmosphere are significant.

COMPARISON OF SURFACE FLUXES OF CO_2 AND H_2O IN DIFFERENT SIBERIAN FOREST ECOSYSTEMS

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Turbulent fluxes of CO_2, H_2O and sensible heat were measured above three different forest types in the Siberian taiga by means of the eddy covariance method during July 1996. Additional measurements of environmental variables, biomass and soil carbon content were carried out to determine the carbon budget of these different but typical forest types. Soil evaporation rates were determined by lysimeter measurements.

The measurement sites were located in Western Siberia about 60 km west of the Yenissey River (89°08'E, 61°43'N, 300 m asl). The three stands, a 6-year-old on a logging area replanted pine stand (*Pinus sylvestris L.*), a lichen desert sparsely stocked with pine and poplar (*Populus tremula L.*) and a well watered and nutrient supplied 35-year-old dense pine stand showed quite different behaviours in CO_2 and energy exchange rates. CO_2 and water vapour exchange of the well watered and healthy growing stand was about 3 to 4 times higher than that over the other two stands regarding the same periods. Nocturnal fluxes showed high variability in CO_2 exchange among the three stands

EFFECTS OF INCREASED CLOUDINESS AND WATER TABLE CHANGES ON CARBON BALANCE IN ARCTIC PEATLANDS

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To assess the effects of possible climate changes resulting from increased levels of greenhouse gasses in the atmosphere on the carbon balance of Arctic regions, carbon balance was investigated in microcosms of three different ecotopes of sub-Arctic peatlands under early summer and mid-summer canopy conditions. Carbon dioxide exchange rates in the microcosms were measured by Infrared-Gas-Analysis after photon flux density, water table and both combined were manipulated. A lower photon flux density alone (simulating increased cloudiness) decreased canopy photosynthesis, whereas respiration remained constant, resulting in a shift in the annual CO_2 budget to net carbon dioxide efflux. If lower photon flux densities were combined with higher water tables (increased precipitation), the decrease in canopy photosynthesis was compensated by a greater decrease in microcosm respiration, and the ecosystem remained a carbon sink. Water table changes produced large effects on microcosm respiration, and smaller effects on canopy photosynthesis. Overall, these results suggest that sub-Arctic peatlands may show a compensated response in their carbon budget, as long as increased cloudiness is combined with increased precipitation. Hence, these ecosystems would remain a carbon sink. If increased cloudiness is combined with unchanged or lowered water tables (e.g. fog instead of rain), the ecosystem would dramatically shift to a net carbon source.

BAHC03 Mountain eco-hydrology

Convener: Becker, A.
Co-Convener: Lang, H.

Critical loads of acidity and sensitive areas in the Slovak Republic

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BAHC03 Mountain eco-hydrology

One of the important issues in protecting of enviroments against impact of acidic deposition is to evaluate and set limits on deposition acidic compounds according to the effects on the ecosystem The limits, or **critical loads of acidity** to an enviroment, is defined as "the highest deposition of acidifying compounds that will not cause changes leading to long harmfull effects on ecosystem structure and function". The calculated exceedance values for surface and ground waters were highly negative values in the greatest part of Slovak Republic, i. e. they indicated that there are certain buffering capacity for further acid deposition.

From the geological background point of view, the most sensitive areas to input acidification compounds are built by crystalline complex (granitoids and variable metamorphic sequences) in the high mountain regions (High Tatras). Furthemore, relatively high sensitivity is charakteristic for all lowlands on the whole territory of Slovak Republic.

ENERGY BALANCE, WATER BALANCE, AND CHANGES OF GLACIERS IN AN INLAND WATERSHED OF THE TIANSHAN MOUNTAINS

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A comparative analysis is made on the components of energy balance between a glacier and the alpine meadow at the high–mountain zone in the Urumqi River basin of the Tianshan mountains during the ablation season from June to August. Both the glaciers and the alpine meadow create an energy sink area of the high–mountains. The energy received by the glaciers is consumed by the ablation of ice and snow, while that by the alpine meadow is mostly consumed by evaporation. In the watershed, the altitude gradient of precipitation varies seasonally. The variatian of both summer and annual precipitatian with altitude shows two maximum value zones, one is located at about 1900m a.s.l. and another at about 4000m a.s.l.. Along with the increase of the mean altitude of the mountainous drainage basins, the basin precipitatian increases, evaporation reduces, runoff coefficient raises and the role of glacier net balance is enhanced in the basin water balance. Finally, an algorithm is developed based on the energy balance model to calculate the change of the glaciers in the watershed under the climate warming, and the results are presented and discussed.

RUNOFF SIMULATIONS OF MOUNTAINOUS AND HILLY BASINS TAKING INTO ACCOUNT VERTICAL GRADIENTS OF AIR TEMPERATURE

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Data sets of several mountainous and hilly basins have been used for simulations of precipitation - runoff process, e.g : Lange Bramke in Harz Mountains, Jalovecký Creek in Tatra Mountains in Slovakia, Langtang basin in Nepal. One common phenomenon governs the runoff generation, i. e. snow accumulation and melt process which is highly affected by changes of air temperature with altitude. The contribution tries to illustrate the sensitivity of annual cycle of runoff to the variability of snow deposits which are further influenced by vertical gradients of air temperature. For runoff simulations the Sacramento model has been used in connection with Anderson's snow submodel which allows to evaluate areal variability of snow deposits. The simulations show that vertical gradients are decisive phenomena for both short time intervals and in long-term processes. On daily time scale namely the inverse meteorological situations may cause 'noises' in case of lacking observations at higher altitudes. In high mountains, difficulties may be encountered in simulations namely by the carryover of snow deposits from one year to another. Other demonstration will concern the snowmelt factor, i.e. the parameter which is related to the vegetation cover. This could be interesting for hilly regions of Central Europe, where the extensive deforestation occurs.

VEGETATION MAPPING AS A TOOL FOR ESTIMATING THE HYDROLOGICAL BALANCE OF ALPINE LANDSCAPES: THE CATCHMENTS OF THE DRINKING WATER RESOURCES OF VIENNA AS AN EXAMPLE

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Large scaled vegetation maps of the alpine and subalpine zone are made up within the framework of the Karst Research Programm of the City of Vienna for the protection of the headwaters and the optimal use of waterresources in the Northeastern Alps. For the capture, storage and display of spatial vegetation data the Geographical Information System ARC-Info has been applied. Vegetation distribution patterns are derived from spatial distributed ecological conditions. Cartographically reported vegetation units such as alpine grassland, vegetation in snowbeds or krummholz show specific hydrological features. Furthermore alpine and subalpine vegetation correlates strictly with soiltypes. Vegetation Soil Units are functionally homogenous, so-called Ecotops. To estimate hydrological parameters such as Interception, Evaporation and Infiltration we use a method of deductivly and inductivly generated data. The deductive way presents a top-down approach and makes use of results from experimental research which have been carried out in comparable vegetation units. The inductive data are the vegetation map itself, a soil map and geomorphological factors from a Digital Elevation Modell. Changed vegetation patterns, induced by e.g. global change, reflect the changed hydrology of the investigated catchment areas.

THE INFLUENCE OF CHANGES IN LAND USE AND CLIMATE ON WATER BALANCE AND RUNOFF IN SMALL CATCHMENT AREAS OF SUBDUED MOUNTAIN RANGES

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Since 1988 hydrological investigations regarding the influence of weather and land use on water balance and runoff formation have been carried out in representative small catchment areas in the hills of southern Niedersachsen (Garte, Wendebach) and northern Hessen (Ziegenhagen). In order to regionally differentiate vertical water flow in Ziegenhagen and to classify areas contributing to runoff, water balance and runoff were simulated over many yearly cycles using the program WASMOD (developed by the 'Projektzentrum für Ökosystemforschung', Kiel). These simulations show that certain relief-soil areas (close to a brook, clayey-silty soils with high water capacity) control a large part of total runoff. On this basis the impact of changes in land use (50% deforestation - classified by useability) and temperature rises in central Europe due to doubling of the CO_2-content predicted by climatic models (atmosphere-ocean GCM's) on runoff formation are examined. The results of the simulation are evaluated with respect to natural variations in runoff. Furthermore, by simulating regionally classified 'pedohydrotopes', it can be shown which subcatchments react strongly on changing boundary conditions.

SPATIAL DISTRIBUTED MODELLING OF EVAPOTRANSPIRATION AND WATER BALANCE IN A HIGH ALPINE CATCHMENT

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Mountain catchments are characterized by a strong spatial variability of topography, surface and soil characteristics, of the climatic conditions and by a long lasting snow cover. The modelling of the hydrologic processes in such a catchment requires particular efforts in the consideration of these spatial variations. A complex hydrologic model was used for the simulation of evapotranspiration and the water balance and runoff components in the alpine catchment of the Dischma-river for the period 1993-1995. The catchment is located in the eastern part of Switzerland near Davos covering an area of 43 sqkm and ranging in elevation from 1710m to 3131m a.s.l. In average the basin is snow covered during 230 days of the year.
In the hydrologic distributed modelling the catchment was spatially subdivided into subareas (hydrotopes) using a GIS with the assumption of a hydrologic similar behaviour within this hydrotopes. The spatial interpolations of the meteorological input variables were employed for each altitudinal zone. The structure of model components for snow accumulation and melt, interception, soil water storage and uptake by evapotranspira-tion, runoff generation, and flow routing is described including the discussion on the assessment of various parameters in their dependence on landuse and time. The results are discussed for each of the hydrologic components with respect to the different altitudinal zones. The influence of topography, of landuse and soil characteristics and of the snow cover on evapotranspiration was investigated and compared to field measurements.

EFFECTS OF ALTITUDINAL GRADIENTS ON WATER RESOURCES IN THE UPPER HARO RIVER BASIN, PAKISTAN.

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The Kahanpur Dam, 35Km. northwest of Islamabad was constructed in 1983 for water supply to the capital of Pakistan The catchment area (777 sq. Km.) with a steep gradient (2744 - 549 meters) i.e. nearly 2134 meters in 48 Km is greatly effecting the storage capacity of the reservoir because of excessively high erosional rates. A total of 15% reduction in water storage capacity has been measured over the last 13 years. Repeated Shale/Clay layers of the alternate Limestone- Shale- Sandstones of Tertiary sequences show considerable decrease in strength on saturation and enhanced erodibility. A large number of Monsoon related landslides also contribute to silting. Various geotechnical tests as Grain size, Atterberg Limits, and Strength on Shales/Clays were carried out for their relation with erodibility and effect of precipitation. Detailed geological mapping and extensive testing were carried out to highlight these effects on sub-basins in the catchment area

Modeling the Spatial Distribution of Evapotranspiration in Mountainous Regions

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A spatially distributed model for the simulation of evapotranspiration has been set up. It includes a spatial raster modeler, which creates the necessary meteorological, land-surface and soil-physical input parameter fields both from remote sensing and conventional data sources, a kernel SVAT-model, which does the actual modeling on each raster cell based on the Penman-Monteith equation and a postprocessing unit. The influence of environmental factors like temperature, water stress and humidity are included in the phyiological part of the kernel model. The model is run at a spatial resolution of 50m during several growing seasons and applied to the Ammer-watershed (app. 600 km=FD) in the Bavarian Alpine Forelands. The main land-uses are meadows and forests. The watershed spans an elevation difference of 1200 m and shows strong gradients in soils, temperature and rainfall, which leads to evapotranspiration limitations of the vegetation. Modeled evapotranspiration is compared with measurements. Both station data and satellite derived temperature fields are used for validation.It is shown that the modeled evapotranspiration distributions compare well both with observations of surface temperature and the water balance.

KRYOSPHERIC LINES IN THE MOUNTAINES AS INDICES OF CLIMATE AND ITS CHANGES.

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Climate changes in the mountains are not registered adequately by observation net because it is very sparse there, unrepresentative and operates in extremely hard weather condition. Vertical zonation is very sensible to both climate and land use changes. Kryospheric lines deal only with climate and thus help to divide factors. The main kryospheric line is *Equilibrium line* on the glaciers. Ablation (A) and accumulation (N) there are equal to each other by definition. Ablation could be determined from summer air temperature. That gives possibility to assess the solid precipitation with the accuracy of the extrapolation of air temperature. The additional lines on the glaciers are the borders between the percolation zones in the accumulation areas. *Lower limit of dry snow zone*, where is no melting ($A = 0$) corresponds to the average summer air temperature about - 9deg.C. *Low limit of snow-firn zone*, where water does not percolate below one-year accumulation layer, corresponds to the relation $A = 0,1N$. *Low limit of cold firn zone*, where all the pores are filled with refreezing percolated water, corresponds to the relation $= 0,5N$. *Low limit of permafrost* corresponds to the level of equal sums of early positiv and negativ degree-days. *Trim line and moraines* correspond to the past positions of glacier terminus wich correspond to the relation $A =$ *$*sina$, where V is glacier velocity.

ECOPHYSIOLOGY OF NORTH-WESTERN NEPAL HYMALAIAN SPECIES

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The impact of global changes are forecasted to be particularly relevant over the mountainous areas of the world. Nevertheless, due to logistic difficulties, studies on tree species growing in high elevation have been seldom performed, particularly in the Hymalaian region. In Sep-Oct 1994, a scientific expedition was organized and realized in the Jumla region (Northwestern Nepal). The aims of the expedition were to study the structure, biodiversity and ecophysiology of the forests of the area. Physiological and structural measurements and sample collection were carried out along a 180 km trek, from Jumla village to Rara lake National Park, encompassing a range of altitude from 2400 to 4000 m a.s.l. The study area is located in North - West Nepal and it is denominated Humla - Jumla region, within the administrative Mugu Karnaly district. The area is wetter and richer in vegetation than the close Dolpo region and less disturbed by tourism. Five conifers and four broadleaved (two evergreen and two deciduous) species have been studied. Classical structural parameters have been collected (tree heights, diameters, density, etc.). Particular emphasis was given to biodiversity indexes, evaluated for the tree and shrub layers along all the trek. Portable instruments have been utilized to measure different ecophysiologycal parameters as net photosynthesis (light-saturated values and light response curves) and efficiency of photosystem II (fluorescence techniques). Hydric status was estimated through leaf water potential. Leaf and wood samples have been collected and analyzed for nitrogen and carbon isotopic content. Soil humidity and respiration have been also measured. Results for the different species along the altitudinal gradient will be presented. Preliminary conclusion about the ecophysiological adaptation to environmental conditions will be drawn.

Relationships between vegetation, soil depth, plant root density, land use, and topographic information on an alpine hillslope.

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B. Ostendorf, E. Tasser, and J. Mulser

Alpine environments are characterized by steep environmental gradients strongly influencing exchange processes between atmosphere, biosphere, and soils. Vegetation pattern can be considered as temporal integrators of environmental conditions as well as land use, which in turn reflects long term averages of exchange processes. Understanding pattern is therefore a mandatory requirement for an understanding of processes. Vegetation has been mapped at a spatial extent of approx. 10 km2 at a high spatial detail. In addition, a high replication of soil depth and root density data have been collected. The physical environment of the hillslope (South Tyrol, elevation range 1400-2200m) is classified by spatial indices based on digital terrain data. We use soil moisture storage, lateral water flow, wind shelter, irradiation, and temperature gradients in our models. Management intensity is best correlated with the distance to roads and slope angle (suitability for machinery). By the means of quantitative spatial modeling, the interactions between the vegetation, below ground rooting pattern, the physical environment, and management intensity are analyzed. The best predictors for vegetation types in the examined area are intensity of management, morphology, and elevation. Root density is highly correlated with vegetation types and land use. Consequently, a very important factor for spatial heterogeneity of pattern and processes affecting the water balance is due to the management decisions of land owners. This study is part of the EU framework IV project ECOMONT (Ecological effects of land use changes on European terrestrial mountain ecosystems).

ECOHYDROLOGICAL PROCESSES ALONG ALTITUDINAL GRADIENTS

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The abiotic environmental variables such as radiation, temperature, humidity, precipitation, wind velocity, and soil moisture influence not only the development of a plant stand but also the processes of the hydrological cycle. They depend on the synoptic situation of the investigated area, the soil conditions and the local climate. The latter is in mountainous regions chiefly dependent on the altitude. Consequently, under otherwise equal climatic and soil conditions the interrelationship between vegetation cover and hydrological processes in mountain areas is greatly influenced by the altitude. In several locations in south-eastern Saxony, different in their altitude, equal concerning their soil conditions and similar in plant stand, we measured the abiotic environmental factors mentioned above as well as the rates of the controlled ecohydrological processes like interception, transpiration, runoff formation, percolation etc. The results obtained by experiments and modelling provide an insight into the complex and temporally varying ecohydrological processes, dependent on the altitude of the investigated area.

HYDROECOLOGICAL PROCESSES ARE AFFECTED BY LAND USE/LAND COVER CHANGE: A WATERSHED CASE STUDY FROM SIKKIM HIMALAYA

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Hydrological cycle in the most important ecological process that determines the structural and functional dynamics of a mountain ecosystems. Information on land-use/cover and hydrological linkages in the Himalaya are very important for considering management strategies. Therefore, the hydroecological parameters were estimated and correlated with land-use/cover. The agricultural land and waste land have increased by 109% and 18%, respectively, at the cost of forest cover from 1988 to 1992. The stream discharge was highest in rainy season and lowest in summer. The over land flow was highest in cropped area (9.6% of precipitation) and lowest in cardamom based agroforestry (2.2%). Soil loss was highest (477 kg /ha) in cropped area and lowest in forest area. This indicating that the conversion of forest to agriculture land use and waste land considerably affected the hydroecological cycle and subsequently the climate. An integrated approach for management of the agroforestry practices are more promising that provide forest cover to enhance soil, water and nutrient conservation, and also improve the socio-economic status of the upland farm families by higher cash return.

EVALUATION OF CLIMATIC REGIONAL WATER/ENERGY EXCHANGE FOR MOUNTAINOUS TERRITORIES

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A method was developed for the evaluation of large-scale climatic water and heat balance components in any terrain using simple commonly available land cover and climatological data sets. It includes preparation of input land cover information, local vertical energy/water exchange model, scheme of lateral water transport by rivers, and output preparation procedures for mapping programs. The local model was tested for different natural conditions during PILPS experiments and improved in some blocks. In this study, the model was applied for extremely dissected and heterogeneous terrain of Himalayans and surrounding territories. The commonly available land cover data sets used for have the spatial resolution of 1x1 degree, and the climatological data sets are of monthly temporal resolution. A data set containing relief dissection parameters with the same spatial resolution was created for the main territory of Eurasia. Results of calculations for the Ganges-Brahmaputra basin (including Tibet and Himalayans) show that even with so poor resolution both by time and space, one can obtain regional maps of heat/water balance components for the hardly studied mountain region. The main features of water and energy cycles in were reproduced quite satisfactorily. The location of evapotranspiration and runoff extrema is connected with relief and natural conditions. One can study interactions between hydrologic and climatic processes at regional scale by this approach. Too rough temporal resolution are planned to be improved in future by inclusion of "weather generator" procedure.

GLOBAL CHANGE RESEARCH ISSUES IN THE FRAGILE HIMALAYAN ECOSYSTEM - CASE STUDY OF WATER RESOURCES

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Himalayas are receiving fresh attention for their multi-purpose utility. Besides supporting traditional terrace agriculture and forestry, the Himalayas are the source of rivers like the Ganga, the Indus and the Brahamputra, centres of biodiversity, attractive sites for tourism and developmental projects. Thus, there is need to reorient our research strategies for the Himalayas in the light of recent challenges related to global change and programme areas which are included in Chapter 13 of Agenda 21 with regard to all mountains. With the increasing population growth and the increasing demand of land for developmental purposes, forest areas and water bodies are getting enormous pressures. Recent changes in land use have brought significant changes in land quality, water flows, nutrients, sediments, pollutants and threat to ecohydrology. The issues concerning sustainability are the function of varied geographical environment, vagaries in the monsoon climate, socio-economic conditions, traditional culture, population growth and poverty. Under such conditions a situation of uncertainty has been created, which also manifests itself in the depletion and degradation of water resources. The region is exposed to high proportion of hydrological disasters and extreme events due to a heightened degree of instability. Environmental degradation particularly that of land and water, constitute a major threat to the livelihood of millions of people. A few experimental studies conducted in the region have shown that water run-off and related effects of erosion and siltation in river basins can be effectively reduced by creating water reservoirs in upland zones.

Geochemical Fluxes in the altitudinal gradient in the Periyar river along the Western Ghats in India.

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The Periyar River in the Western Ghats has a highly undulating topography with steep drop in altitude at several places. The highest peak 2700m in Peninsular India and outside the Himalayas is the catchment of the river. Within a very short distance of 50 kms, the altitude drops in series to mean sea level, through narrow plains to the Arabian sea. With extreme rainfall conditions from 250 cm/yr to 500cm/yr in the catchment, the basin is rain dominated due to the south-west (60%) and North-east (25%) monsoons. There is a moderate cool upland (Temperature-10°C in winter) the humid tropics in the coast (Temperature 31°C) within a short distance of about 200 kms. The landuse pattern is less than 15% forested in the catchment and more than 50% plantation in mid and downstream with patches of wasteland throughout.

Geochemical studies were initiated to monitor nutrients in water and sediments and also quantify erosion and soil loss. Dissolved phosphates vary from 0.18 mg/l in the catchment to 0.06 mg/l in the coast during monsoon and from 0.11 to a 0.02 mg/l during low flow seasons with a very high of 2.7 mg/l dissolved phosphate near wasteland regions. The sediment bound phosphorous varies from a low of 300 µg/gm to a high of 1300 µg/gm irrespective of altitudinal constraints due to monsoonal distribution of eroded soil. The loss of dissolved phosphate due to chemical erosion in the steep gradient basin is ten-fold with a low of 20 tonnes/year dissolved phosphate in the catchment to a high of 200 tonnes/year in the river mouth at the coast. Thus, it is an ideal small basin to test some of the BAHC objectives.

THE MAIN EFFECTS OF NATURAL EXPERIMENT BY EXTENSIVE DE-FORESTATION IN MOUNTAINOUS CATCHMENTS OF S-W POLAND

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Process of gradually defeat, becoming ill and decline of Norway spruce stands is an effect caused by anthropogenic distant sources of air pollution.
This paper report the results of a long term catchment study of forest decline in a region of so named „Black Triangle" near borders of S-W Poland, Czech Republic and Germany (Ost.). The study was conducted mainly on the upper Kamienna river and several other catchments in The West Sudety Mountains. During the first ten years period the forest cover of catchments decreased by about 85% at higher elevations (>800 m a.s.l.) and by about 50% at the lover elevations. Monitoring of outflow and precipitation in years 1975-1994 indicates a significant increase (relative to precipitation) of water yield and some other changes. Developed by a rapid growth of grass a thick sod changed unfavourably hydrological function of soil and increased wind and direct insolation caused loss of soil moisture. However, these factors seem to be overcompensated by reduced transpiration of spruce trees and by smaller interception loss. Deforestation as a whole caused: increase of minimum and average discharges by 10 to 15%; vernal discharge set on up to 25 days earlier and has increased by some 30% as before deforestation, the predicted increase of peak discharge values, for flood events with lower probability, will be 40-110% by level of near complete deforestation. In last four years (1991-1994) interpretation of measurement data indicates a slow decrease of discharge in regenerated (afforested) catchments.

DISTRIBUTED MODEL FOR MOUNTAINOUS FUJI BASIN, JAPAN

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A distributed hydrological model of 1 X 1 km mesh resolution is proposed for the Fuji river basin of 3400 km^2 in central Japan, a basin of steep altitudinal gradients. First, altitude and gradients of all meshes are picked out from GIS database, and monthly and daily meteorology in mesh is created by a step-wise regression interpolation, including altitudinal effects. Second, core model for meshes and hydrograph routing module for river network are constructed into the distributed daily-run model, simulating snowfall and melt, rainfall interception, soil water and various outflow, and groundwater. Parameters are determined by basin topographical and GIS information. Model works well. Third, response of mountain hydrology to lansuse change is analyzed.

OCEANS AND ATMOSPHERE (OA)

OA1 Open session on ocean circulation: physics of water mass transformation

Convener: Böning, C.
Co-Convener: Osterhus, S.

IDENTIFICATION OF MEDDIES IN NE-ATLANTIC BY HISTORICAL DATA

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Data collection for NE Atlantic contains more than 45000 CTD, XBT and Bathometric historical stations and consists of direct observation of P.P.Shirshov Institute of Oceanology, a number of special French, American and WOCE expeditions, and also includes data of Obninsk World Ocean Data Center and World Ocean Atlas - 1994 (NODC). On the base of recent observations a search for presence of Meddies in mean salinity and temperature field is made, with a positive salt anomaly of at least 0.3 psu. The distribution of positive anomalies of salinity was a form like a "comet train" oriented in SW. This work is supported by RFBR grant N 96-05-65287.

THE DISTRIBUTION OF TRITIUM AND HELIUM IN THE SUBPOLAR NORTH ATLANTIC

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Samples from the subpolar North Atlantic, the Labrador Sea and the Area north and south of the Greenland-Iceland-Scotland-Ridge system taken during several cruises in 1991, 1992 and 1994 were analyzed for their concentrations of tritium and helium. From the transient input of tritium to the ocean surface and the enrichment of ^{3}He in subsurface waters ventilation ages of water mass renewal by winter convection may be assessed. Furthermore, comparison of tracer data obtained at different locations and times permits to discribe the pathways of water masses and to estimate mean residence times and transfer veliocities.
Convective renewal from the surface contributes to the overflow waters at the Greenland-Iceland-Scotland-Ridge (DSOW and ISOW) and to LSW in the Labrador Sea. The tracer distributions in the deep water masses of the subpolar North Atlantic are discussed in relation to the signals observed in the overflow areas and in the Labrador Sea. Water mass modification caused by mixing as well as mean renewal times and transfer velocities are estimated.

A METHOD FOR IMPROVED REPRESENTATION OF DENSE WATER SPREADING IN GEOPOTENTIAL-COORDINATE MODELS

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The spreading of bottom water masses over sloping topography is not well represented in hydrostatic geopotential-coordinate ocean circulation models because convective adjustment introduces excessive water mass dilution. We present a technique for incorporating the process of near-bottom tracer transport over sloping topography based on a "hybrid" approach, coupling a simple terrain-following bottom boundary layer model to the standard ocean general circulation model. Two examples are presented to illustrate the method and its impact on the model dynamics: (a) idealized and well resolved experiments focussing on advectively dominated down-slope penetration of a dense water plume over a linear slope, and (b) experiments with a non-eddy resolving model of the North Atlantic circulation, where the spreading of Denmark Strait Overflow Water is mainly diffusive. The results of these applications suggest that the method is helpful for both high resolution biogeochemical coastal modeling studies and coarse resolution global climate simulations.

Winter convective events and decadal convection in the Greenland Sea

Gereon Budeus and Wolfgang Schneider

From a series of observations during four successive years two items are adressed. The convective status of the Greenland Sea between 1993 and 1996 is investigated with the main result that not only convection to deep waters did cease in that time interval but also ventilation of intermediate waters was extremely restricted. This fact allows to adress the second item, which is the development of a concept for deep water renewal under the absence of winter convective events that explains both the changes in physical properties in the deep water of the Greenland Sea (continuous warming) and the simultaneous changes in tracer concentrations (e.g. increasing Freon contents). Hereby the contradiction between the need for a certain rate of deep water production, which arises from the tracer observations, and the absence of deep convective events as seen from physical measurements is resolved.

SENSITIVITY OF AN OCEAN GENERAL CIRCULATION MODEL TO PARAMETERIZATION OF DENSE BOTTOM DOWSLOPING FLOW

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In the world ocean, highest density are found on the continental shelves, mainly near Antarctica, and are responsible for density driven, downsloping currents that could influence the deep ocean water masses properties. This process is badly represented in z-coordinate models, especially in GCM with coarse resolution in both horizontal and vertical directions. Here we present a simple parameterization of downsloping flow, designed for GCM : at the shelf break, the dowsloping current is evaluated from the horizontal density gradient between the two adjacent boxes, using a linear relation, and is directly incorporated into the deepest level with lower density. This parameterization has been implemented in the UCL Ocean GCM and two experiments, without and with this scheme, have been integrated until equilibrium, using an annual mean forcing. The impact of this parameterization on the global ocean is dominated by the improvement of the Antarctic Bottom Water, which tends to reduce the intensity and depth of the North Atlantic Deep Water circulation and increases the density of the deep ocean. Shelf water is also improved: As a consequence of an higher exchange with the open ocean, the results show a reduction of the Antarctic shelves salinity.

EFFECTS OF THE DRAKE PASSAGE ON THE GLOBAL OCEAN CIRCULATION

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The effect of the Drake Passage on the global ocean circulation was investigated by two parallel integrations (5 years) of a coupled atmosphere-ocean model developed at NASA/Goddard Institute for Space Studies with: (1) a realistic topography, and (2) a closed Drake Passage. Both cases were initiated from the NCEP atmospheric observations for 1 December 1990, and from the NODC December temperature and salinity fields. Comparison between the two runs shows the effects of the Drake Passage closure on the global circulation: (1) strengthening the overturning and in turn increasing the meridional transport of heat, mass,and momentum; (2) increasing the through-flow between the Pacific Ocean and the Indian Ocean; and (3) increasing the equatorial currents.

THE VARIATIONS OF THE AIR PRESSURE, AIR TEMPERATURE AND SEA LEVEL CAUSED BY THE MOTION OF THE MOON AND THE PLANETS.

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There are discovered the line structure of the power spectra in range of periods from 5 days to 4 years of the time variations of the air pressure, air temperature and sea level, which are observed during the 40 years on the coast of Japan sea (points Terney and Holmsk).The frequencies of the lines are the same for spectra of variations of sea level, air pressure and air temperature. The spectra looks like the same as the spectra of the electromagnetic emission of the molecules. The frequencies of the separate lines can be juxtaposed with frequencies of planets (Jupiter, Venuce, Mars) and Moon rotations and with the combinations of the frequencies of the these processes and frequency of the Earth rotation around the Sun . The main maxima correspond to period and semiperiod of the Earth rotation around the Sun . The next ones are the combinations of frequemcies corresponded the Moon, Jupiter, Venuce rotations. Inside the different lines of combinations corresponded to the same Planets the main one is the synodical line.

Deep-ocean convection simulation based on multi-layer heton model

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A spreading stage of an open-ocean deep convection dominated by rotation is considered. For that purpose, a multi-layer quasigeostrophic model of point baroclinic vortices (hetons) is developed. Using this model, we investigate both analytically and numerically dependence of horizontal heat transport on the vertical distribution of a potential vorticity anomaly generated during preconditioning and mixing phases. Model runs were performed for the case of cooling area in the form of a stripe which can be associated with a cold air outbreak over sea, with 2π periodic boundary conditions in one of horizontal directions. It is found that clustering and heat fluxes are sensitive to the vertical distribution of PV anomaly. A linear stability analysis is carried out for a stripe of homogeneous heton-like potential vorticity distribution. Instability increment and wavenumber are analyzed as a function of the model vertical structure and are found to be in agreement with numerical simulations. Results of heton model compare reasonably with predictions of LES modeling.

THE FATE OF THE NORTH ATLANTIC DEEP WATER THROUGH THE WORLD THERMOHALINE CONVEYOR BELT

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The route and the transformation of the North Atlantic Deep Water (NADW) is studied in a general circulation model (OCCAM). The NADW is followed by Lagrangian trajectories from its formation in the North Atlantic until it is converted into another lighter water mass, forming hence the deep branch of the world thermohaline conveyor belt.

The major region of upwelling is the Southern Ocean where 9.3 Sv (59%) of the 15.8 Sv of NADW is ventilated along the isopycnals. Most of this is located south of, or in the southern part of, the Antarctic Circumpolar Current. The second most important area is the highly eddy active region of the Agulhas with 1.3 Sv (8%). The equatorial upwelling is constrained to within a few degrees either side of the equator. This upwelling is only 1.1 Sv (7%), which is rather small compared to the traditional view of strong Equatorial upwelling. The rest of the water is more evenly upwelled over the ocean with stronger upwelling in regions of high eddy activity and western boundary currents.

ON THE FORMATION OF SUBTROPICAL MODE WATER IN THE SOUTHWEST ATLANTIC

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In the South Atlantic, Subtropical Mode Waters are observed in the south western part of the subtropical gyre. They are formed by winter convection of the warm and salty water of the Brazil Current waters which overshooting towards latitudes higher than 40 S are submitted to a strong cooling. Historical hydrographic data and more recent cruises show changes from year to year in the characteristics (temperature and salinity) of the Subtropical Mode Water. The region of mode water formation is a location where the annual heat loss from the ocean to the atmosphere exhibit a quite high interannual variation. In June 1995, 5 surface drifters, equipped with meteorological sensors and a 150 meter long bathythermistor chain, were deployed in the Brazil Current overshoot region to study the Mode Water formation. These buoys remained trapped in the Brazil Current recirculation cell and thus provide information on the recirculation itself and on the eddies embedded in the recirculation. We simulate the formation and characteristics of subtropical Mode Water characteristics with a 1-D lagrangian model following buoys' drifts in order to examine what are the key parameters involved in the subtropical mode water formation (sensitivity to the interannual fluxes variations, role of the oceanic mesocale..).

Gradual Warming of the Weddell Sea Deep and Bottom Water

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The Weddell Sea is one of the areas of major water mass modifications in the ocean. Deep and bottom water is injected into the circumpolar water belt from where it spreads as Antarctic Bottom Water into the basins of all three oceans. Between October 1989 and May 1996 five cruises with "Polarstern" were carried out in the Weddell Sea. The repeated surveys in the southern and the central Weddell Sea and the temperature time series of moored instruments show a consistent increase of the temperature in deeper layers of large parts of the Weddell Sea. The warming is most pronounced in the Warm Deep Water layer which results from the inflow of Circumpolar Deep Water into the Weddell Gyre. We conclude that the inflow from the Antarctic Circumpolar Current into the Weddell Gyre is either enhanced or has changed its characteristics since 1984. From 1992 to 1996 the warming propagated fom the Warm Deep Water level into larger areas and deeper levels in particular north of Maud Rise. It is related to the change of the shape of the Weddell Gyre which was split into two distinct domes in 1992. The southern one centered at 62°30'S vanished between 1992 and 1996. The variation of the major source water mass can be followed from the central to the western Weddell Sea. It leads either to a reduction of the bottom water formation or to a change of the characteristics of the recently formed bottom water. The temperature increase spreads from the west to the east and vertically. It is most pronounced in the Warm Deep Water and the Weddell Sea Bottom Water layers and barely noticable in the Weddell Sea Deep Water.

MODERN AND GLACIAL CIRCULATION OF THE ATLANTIC OCEAN

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To simulate modern and glacial circulation in the Atlantic Ocean, an ocean general circulation model is first driven by prescribed boundary conditions and second by temperature forcing fields supplied by an energy balance model.
With fixed boundary conditions the recent circulation is well reproduced. However, the results using glacial boundary conditions are inconsistent with our current understanding of glacial circulation patterns. A fundamental cause is the tuning of free parameters to today's conditions, which in some cases provides inadequate results for 'glacial' experiments. Dense water produced in the Nordic Seas does not affect the North Atlantic Deep-Water (NADW) in the model as much as measurements suggest. To compensate this model artefact for today's conditions, the parameterization forestalls the simulation of the glacial circulation.
Results of the coupled ocean – energy balance model allow to investigate the impact of the sea ice and corresponding salt fluxes on ocean circulation. It becomes obvious that the coupled model requires a more complex sea ice model. A moderate change of salt fluxes resulted in circulation patterns, which are consistent with geological data of the last glacial maximum. Furthermore, the resulting SST and sea ice distributions in equilibrium
are in good agreement with the data of CLIMAP (82), which recently were suspecte d to be too cold.

SENSITIVITY STUDY WITH AN OCEAN / ENERGY BALANCE MODEL AND DIFFERENT GLACIAL FRESHWATER FLUXES

Kerstin Fieg (Alfred Wegener Institute for Polar and Marine Research, Columbusstraße, 27570 Bremerhaven, Germany)

For glacial climate boundary conditions a coupled ocean / energy balance model (EBM) is forced by different freshwater fluxes. To drive the ocean model at least wind stress data, sea surface temperature (SST) and a haline forcing field are needed. While the wind stress field is simulated by a complex atmospheric model (ECHAM) (Lautenschlager & Herterich, 90) the SST as second forcing field is modelled by the EBM. For the sensitivity experiments different freshwater flux data sets provide the third forcing field. Their rates only differ in the North Atlantic region and only by less than 0.1 Sv.

While the differences in the freshwater fields are small, the differences in the Atlantic meridional overturning are large. It seems that two completely different circulation regimes exist. The first regime shows a weak North Atlantic Deep Water (NADW) production of 10 Sv and a strong Antarctic Bottom Water (AABW) mass. This pattern agrees with ideas derived from deep sea sediment data. The second regime is dominated by an unrealistically high overturning rate of 42 Sv in the Atlantic.

Furthermore, sensitivity experiments show that the transition between both regimes takes place very fast and is dependent on very small differences (0.02 Sv) in the haline forcing field of the North Atlantic.

RECENT AND GLACIAL DEEP WATER FORMATION BY TURBIDITY PLUMES - NUMERICAL STUDIES

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Turbid water that contains suspended particles is more dense than pure water. To investigate the impact on deep water formation a hydrostatic reduced-gravity plume model was coupled with an eulerian sediment model.

High accumulation areas of fine grained sediments at the sea floor can be used to quantify the deep water formation by turbidity plumes. First numerical case studies have shown that recent deep water formation by turbidity plumes might be in the order of other convection processes.

Since glacial sedimentationrates are higher than recent sedimentationrates deep water formation must be larger also. Numerical studies adjusted to the glacial scenario demonstrate the increased deep water formation especially during the last deglaciation. At that time turbidity plumes could have been the decisive process to ventilate the deep oceans at high latitudes.

A numerical simulation of a turbidity plume due to melt water run off - triggered off the Jökulhlaup at Island - demonstrates the possibility to transport fresh water into the deep ocean.

TRACER DISTRIBUTIONS REVEALING ASPECTS OF THE LARGE SCALE CIRCULATION IN THE EURASIAN BASIN

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In 1993 and 1995, during the R/V "Polarstern" expeditions ARK IX/4 and ARK XI/1, tracer sampling programs were carried out in the eastern Eurasian Basin. The aim of these programs was to investigate the exchange between the shelf seas and the Eurasian Basin, as well as the large scale circulation in the basin's interior. These expeditions extend the data coverage gained from prior expeditions in the western part of the basin and provide the basis for a comprehensive picture of the circulation of surface and intermediate waters.
Combination of ^{18}O and salinity data allow separation of the river-runoff and sea-ice meltwater fractions contained in the Arctic halocline. This provides the basis for tracking the river-runoff signal from the shelf seas across the central Arctic Ocean towards Fram Strait. The mean residence time of the river-runoff fraction in the Eurasian halocline is determined to be about 4.5 to 7 years. Tritium/^3He and chlorofluorocarbon data show the renewal of the intermediate water by the inflow of Atlantic Water that has been modified in the shallow Barents and Kara seas. This water merges with water of Atlantic origin which has entered via Fram Strait, and propagates eastwards along the shelf brake with a mean current speed of about 2 cm/s. Both branches circulate cyclonically inside the Arctic Ocean and exit through Fram Strait.

MULTIVARIATE ANALYSIS OF GEOSTROPHIC AND AGEOSTROPHIC MESOSCALE CIRCULATION IN THE OMEGA PROJECT

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During an intensive survey in the Alborán Sea (OMEGA cruise, October 96) a 80x100 km^2 domain was covered by SEASOAR and ADCP profiles with a spatial resolution of about 4 km along-track and 10 km in-between-track. The domain was centered on the jet of incoming Atlantic Water, with tracks oriented perpendicular to the front in order to achieve a dense sampling of the strong gradients that characterize this region. An objective spatial analysis scheme based on multivariate optimal statistical interpolation allowed to separate the non-divergent and irrotational contributions of the motion field, as well as the geostrophic and ageostrophic contributions of the streamfunction field. Results indicate that multivariate spatial analysis not only allows to estimate the relative contribution of ageostrophic processes, but also can lead to a better resolution of the geostrophic component of mesoscale circulation features than an analysis based only on hydrographic observations. This work is a contribution to objective (1) of the OMEGA project, which is to determine the spatial and temporal variability of the three dimensional ageostrophic circulation in an intense mesoscale upper ocean front .

QUASI-GEOSTROPHIC 3D CIRCULATION IN THE BRANSFIELD STRAIT (ANTARCTICA)

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M. A. García and O. López (Laboratori d'Enginyeria Marítima, Universitat Politècnica de Catalunya, 08034 - Barcelona, Spain)

A dense network of CTD stations (separated 20 km) covering the eastern basin of the Bransfield Strait were used in conjuction with arrays of current meters to estimate the 3D circulation at scales that had not been addressed before. A new analysis technique based on EOFs gave a truly 3D representation of the geostrophic streamfunction and related variables (such as velocity, vorticity and vertical forcing) even in shelf regions shallower than the baroclinic reference level. Results show an overall circulation pattern dominated by the Bransfield front and its associated jet-like current (the Bransfield current), which cross the northern half of the basin with a predominant SW-NE direction. Dynamically significant mesoscale features (relevant down to 450 dbar) appear to be mostly associated with the meandering of this current. A secondary, shallower frontal structure separates the Transitional Zonal Water with Bellingshausen Sea influence from the Transitional Zonal Water with Weddell Sea influence, but it has limited influence on the geostrophic circulation. A related consequence of the observed circulation is the formation of local water by isopycnal mixing of surface waters from the Bellingshausen and Weddell Seas and deep waters such as Circumpolar Deep Water and Weddell Deep Water.

THE IMPACT OF THE WATER TRANSPORT THROUGH THE CANADIAN ARCHIPELAGO IN A GLOBAL ICE-OCEAN MODEL

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The water transport from the Arctic to Baffin Bay through the Canadian Archipelago is usually neglected in large-scale ocean models. However, estimates of the flow are between 0.7 Sv and 2 Sv, which is of the same order of magnitude as the flow through Bering Strait or as the export of Arctic surface water through Fram Strait. This has led us to investigate the role of the flow through the Canadian Archipelago in our global ice-ocean model. Our study reveals that the transport has a profound influence on the freshwater budget of the Arctic and of the Labrador Sea but also of the Greenland Sea, the freshwater transport through Fram Strait being much smaller when a flow through the Canadian Archipelago is allowed. The modification of the freshwater balance leads to a decrease of convective activity in the Labrador Sea and an increase of this activity in the Greenland Sea. As consequence, the rate of water mass formation as well as the properties of the water masses are modified in these regions.

SPREADING OF MEDITERRANEAN AND LABRADOR SEA WATER MASSES OBSERVED WITH NEUTRALLY BUOYANT FLOATS - PRELIMINARY RESULTS FROM THE EUROFLOAT PROJECT.

John Gould (WOCE IPO, SOC). Michael Sparrow, Vassilis Zervakis, Alán Cantos-Figuerola (AINCO), Olaf Böbel, Walter Zenk (IfM), Kevin Speer, Martin Menzel (LPO, CNRS/IFREMER).

The EUROFLOAT (funded under EC MAST project MAS2CT940102) has deployed eddy-following, acoustically-tracked neutrally buoyant floats of two types (RAFOS and MARVOR) near the core levels of the recently ventilated Labrador Sea and the saline Mediterranean water masses. The RAFOS floats surface only at the end of their mission to download the tracking data to the ARGOS satellites, whereas the MARVOR floats cycle back and forth to the surface every three months transmitting information during their three year mission. Together with MARVOR floats from the French ARCANE project these are starting to delineate the water mass spreading. Float trajectories and associated statistics (e.g. eddy diffusivities, eddy K.E. and integral time scales) will be presented along with a preliminary analysis of the spreading and variability observed. The Azores Current is shown to pass north of Madeira, strongly steered by bottom topography. The early statistical analysis suggests that the mean flow between the Canary Islands and the Azores is not significantly different from zero, whereas the perturbation flow is considerably stronger. This analysis will be strengthened as new float data are collected in the coming months. The observations are complemented by related modelling research not included in the poster.

THE USE OF THE MODEL HYDRODYNAMIC ADJUSTMENT PROCEDURE TO RECONSTRUCT WORLD OCEAN HYDROPHYSICAL FIELD STRUCTURE

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The diagnostic and adjustment calculations of the World Ocean circulation using the Levitus (1994) hydrological information data set with 1 degree grid spacing and 33 vertical levels were carried out. The model of general circulation used for this work (Sarkisyan, Demin, Ibraev) is the version of the Bryan-Cox primitive equations ' model. One of the advantages of this model is that the ocean level is used as an integral function. That is why multi-connection is not a problem when calculating the World Ocean currents: we can take into account the presence of dozens of islands without additional problems. The analysis of the calculation results has shown that the original Levitus data are overfiltered. After hydrodynamic adjustment the temperature, salinity and current field structure becomes more realistic. The most pronounced it was shown in the regions of boundary currents and equatorial areas. The numerical experiments shown that the method of hydrodynamic adjustment can be successfully used to reconstruct the hydrophysical field structure.

CLIMATE DRIFT AND WATER MASS FORMATION IN COUPLED OCEAN-ATMOSPHERE MODELS

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The water mass drift associated to long term climate drift in coupled ocean-atmosphere models is assessed in the coupled CGM OPA/ARPEGE [Guilyardi and Madec 1997]. The ocean GCM includes an explicit oceanic mixed-layer and has two physical parameterisations of the lateral diffusion (horizontal and purely isopycnal diffusion). For coupled and forced experiments, water mass volume budgets are computed for the subtropical mode water (STMW) of the North Atlantic as in Speer and Tziperman 1992 and Garret et al. 1995. They show how the balance between surface formation and interior diapycnal diffusion is affected by the choice of lateral physics. In forced mode, the surface restoring term is shown to ultimately degrade the interior water masses by generating irrealistic surface water formation in regions of strong SST gradients. In coupled mode, the free evolution of the air-sea interface associated to horizontal diffusion in the OGCM cannot maintain a mode water. The isopycnal diffusion is able to maintain the STMW but the amplitude of the annual cycle is too small. This bias is further attributed to reduced exchanges between the seasonal thermocline and the ocean interior and emphasis the role of subduction in setting the water mass characteristics of the world ocean.

DIAGNOSTIC MODELLING OF GEOSTROPHIC AND AGEOSTROPHIC MESOSCALE CIRCULATION IN THE OMEGA PROJECT

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One of the objectives of the OMEGA project is to provide the scientific community with a new and useful tool for computation of vertical velocity from routine CTD and ADCP data, using an interdisciplinary numerical and observational approach. The field studies were carried out during October (BIO Hespérides) and December (R/V Discovery) 1996. Data obtained in 4 consecutive samplings of the same area included Seasoar, ADCP, fluorescence, acoustic backscatter, nutrients, flow-cytometry, lagrangian floats, etc. Preliminary analysis of these data show the existence of significant variability at scales of the order of the internal Rossby Radius. We present the modelling initiatives that are being carried out, using these data as initial conditions. Dynamic models and diagnostic methods are being used to interpret the observations and to diagnose the dynamically balanced mesoscale circulation, including the vertical velocity. These methods include quasigeostrophic (QG), semigeostrophic (SG) and iterated geostrophic (IG) models, as well as the primitive equations based method of digital filter initialization (DFI). The strengths and weaknesses of these methods as diagnostic tools will be reviewed and their general applicability to the OMEGA data sets will be assessed. Preliminary results will be presented and an outline of the next steps in the dynamic analysis of the data will be given.

SIMULATING THE GLOBAL OCEAN CIRCULATION BY FITTING A MODEL TO TRACER DATA

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Hydrographic and Chlorofluorocarbon (CFC) data are assimilated into a global ocean circulation model by means of the adjoint technique. Horizontal flows, surface heat fluxes and mizing coefficientes are optimized under the assumption that mass-, heat-, salt- and tracer conservation are satisfied exactly. The model is stationary. It has non-uniform horizontal resolution and 26 layers in the vertical. The global modelled distributions of potential temperature, salt and tracers that result after assimilation are extremely close to the respective measured distributions. There are two different global ocean circulation patterns, that make this extremely good fit possible. The main differences among them consist of the direction of the surface heat transport in the South Atlantic, and the amount of Agulhas water that enters the Atlantic instead of recirculating into the Indian Ocean. The model integrated mass and heat transports for both solutions will be discussed.

ON THE OVERFLOW AND FORMATION OF THE DEEP WESTERN BOUNDARY CURRENT IN THREE EDDY RESOLVING MODELS OF THE NORTH ATLANTIC

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The outflow of dense water masses from the Nordic Seas into the subpolar North Atlantic plays a crucial role for the thermohaline circulation of the World Ocean. Whereas in the past, the overflow processes entered GCMs as subgrid-scale processes and were thus depending on the numerical formulation of the physical system and the parametrization schemes, the models in the European DYNAMO project explicitely resolve the topographically controlled transport of dense water masses.
The models follow different concepts for the discretization of the vertical coordinate. Results from the intercomparison of a level model (GFDL-MOM), an isopycnic model (MICOM), and a sigma-coordinate model (SPEM) will be presented with focus on the performance of the models in critical regions like the Denmark Strait and the Iceland-Faroes-Shetland ridge system, with respect to recent observations for model validation.

THE EFFECT OF MOMENTUM DISSIPATION PARAMETERIZATIONS IN COARSE-RESOLUTION THERMOHALINE CIRCULATION MODELS

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Different parameterizations of momentum dissipation and associated boundary conditions are compared in an ocean model based on the planetary geostrophic equations. It is used at coarse-resolution for a mid-latitude flat-bottomed basin, with restoring boundary conditions for the surface density and no wind stress. The various equilibrium states obtained are quite similar in term of surface temperature and poleward heat transport. However, traditional Laplacian friction produces an interior circulation in better agreement with geostrophy and Sverdrup balance, but generates excessively large vertical transports along the lateral boundaries. Upwelling in the western boundary current (the Veronis effect) and downwelling in the eastern polar regions enhance the meridional overturning but reduce the deep water density and the poleward heat transport as well. Rayleigh friction with a no-normal-flow boundary condition induces a more efficient thermohaline circulation, with better agreement between convection regions and areas of downward velocities, denser deep water, stronger thermocline stratification and higher poleward heat transport. Vertical velocities along the boundaries, strongly influenced by dynamical boundary conditions, contribute significantly to the total mass and heat balance in such models.

EXPERIMENTAL FRANCO-RUSSIAN OBSERVATION OF MEDDY LOCATED IN AZORES FRONT LOCATION

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The Meddy in Azores front location was located and described. The velocities and volume transports of the barotropic and baroclinic components of current and Meddy's displacement from october to november were evaluated. This work is supported by RFBR grant N 96-05-65287.

AN INFLUENCE OF NON-STATIONARY BOUNDARY CONDITIONS ON THE INTRA-SEASONAL VARIABILITY OF THE HYDROPHYSICAL FIELDS IN THE NORTH ATLANTIC

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The simulation of hydrophysical fields evolution in the North Atlantic from December, 1 1978 to February, 28 1979 using the real daily surface temperature and wind stress data from the First GARP Global Experiment (FGGE) as non-stationary boundary condition was carried out. To evaluate the contribution of wind stress non-stationarity to hydrophysical fields evolution the second experiment was carried out. In this experiment only non-stationary wind stress data from FGGE were used. The analysis of the calculation data has shown that the use of real daily boundary conditions on the ocean surface results in more realistic behaviour of the hydrophysical fields. It was shown that the intra-seasonal variability of the hydrophysical fields in the North Atlantic is essential. This variability must be taken into account to detect intra-climatic trends. The analysis of the calculation results has shown that the essential evolution of current fields and fluctuations of their transport were caused not only by intensive winter convective processes but remarkably by non-stationary wind forcing on the ocean surface. Such an approach can be used to study intra-annual variability of the ocean.

THE DYNAMICS OF THE FLOW IN THE CROZET STORM TRACK

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Altimeter data shows that in the Crozet storm track region there is strong mesoscale variability of sea level. Fine resolution numerical models, namely FRAM and POP, produce a particularly vigorous eddy field in this region. The important question is how transient eddies affect the mean zonal and meridional flow and exchanges of heat and salt between subtropical and subantarctic waters? This question has been studied using the concept of local Eliassen-Palm fluxes, the theory of momentum penetration (Ivchenko, Richards and Stevens, 1996, JPO) and using output from FRAM and POP.
It was shown that the ACC, and especially its northern flank, is strongly affected not only by vigorous westerly winds but by thermohaline processes as well. We find the principal driving force of the ACC in that area is the surface wind stress, however the contribution from the buoyancy driven flow maybe as large as 40%. Mesoscale eddies are found to be responsible in shaping the flow structure and transferring momentum in both the horizontal and vertical. The locations of these transfers is restricted to eddy rich regions associated with a large-scale topographic features.

Parameterisation of dense water formation in subgrid leads and open-ocean chimneys

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In larger scale circulation models convective water mass formation, confined to non-resolved (i.e. subgrid) leads in polar seas, needs to be parameterised. It is argued that - in first order approximation - dense water mass formation is confined to a lead area. A mixing scheme is therefore applied to the sub-volume beneath a lead, whereas the surrounding water body in the respective grid volume remains unaffected. An extended subgrid scheme is formulated that accounts for re-stratification of dense sub-volume water in larger depths. These techniques produce saltier and colder bottom water than conventional techniques, where the surface buoyancy flux in the lead contributes to the entire uppermost grid volume. While the conventional schemes erode an existing pycnocline, subgrid schemes contribute to maintain a pycnocline in the grid-average. Furthermore, subgrid schemes are capable of describing the effect of non-resolved open-ocean chimneys, reproducing results of non-hydrostatic model studies. With conventional schemes the deep water formation in non-resolved chimneys is considerably underestimated. An application of the proposed schemes (for instance in climate models) might lead to a better representation of dense water formation in polar regions.

Stratification effects on thermohaline free convection: nonhydrostatic numerical process studies

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A two-dimensional nonhydrostatic ice-ocean convection model is applied to an initially ice free and stable stratified ocean at rest. A two-layer ocean is exposed to dry and cold polar air during calm wind conditions. Initially, the upper ocean layer is nearly at freezing temperature, the lower layer well above. Our studies show that convective water mass formation is sensitive to the initial stratification of both salinity and temperature, further indicating that effects due to the non-linearity of the equation of state of seawater (cabelling) may contribute to the generation of internal convective mixing. We conclude that convectively induced upward heat transport (a) leads to a weakening of the surface buoyancy forcing, and (b) stabilizes the surface waters due to melting of formerly formed or advected sea ice. Both effects reduce the success in dense water mass formation. Our studies indicate that (event-wise) deep convection in the Greenland Sea is most likely when a surface meltwater layer (forming due to convectively induced upward heat transport) is removed occasionally due to lateral large-scale advection.

VENTILATION OF THE INTERIOR ARCTIC OCEAN IN AN ARCTIC OPYC-MODEL

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Watermasses of Atlantic origin enter the Arctic Ocean through Fram Strait and via the Barents and the Kara Seas. Both branches experience different ambient conditions on their way eastward until they meet again along the continental slope north of the Kara Sea. Processes like heat exchange, ice formation and melt, mixing and interaction wit h riverwater and convection determine to which extent and along which path the two branches will ventilate the interior Arctic Ocean.
An Arctic Version of the coupled ice-ocean general circulation model OPYC (Ocean isoPYCnal model) is set up to be integrated for several decades. The processes affecting the watermass properties of the inflowing branches of Atlantic origin in the model are studied. The water leaving the shelf towards the central Arctic splits into several branches, partly feeding the Transpolar Drift, partly feeding the cyclonic deep slope current where it interacts with the Fram Strait branch approaching from the west. The ventilation of the interior Arctic Ocean by these watermasses will be discussed and compared with observations.

ON THE BENTHIC BOUNDARY LAYER'S DYNAMICS OF THE OCEAN

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The benthic boundary layer (BBL) as a field of oceanology, has been considered by SCOR Working Group 95 "Seabed Properties and Sediment Suspension" on 1993-1996. This layer, like the upper active layer of the ocean, differ markedly in its properties from the main water mass. For this reason, the BBL can be studied separately. On the other hand the BBL has much in common both with the upper active layer and with the atmospheric boundary layer. All of these layers are essentially stratified Ekman planetary boundary layers in which buoyacy plays a major role. The upper ocean and the atmospheric surface layer have been studied far more thoroughly than the BBL, partially owing to the inaccessibility of the latter in the open ocean and the need for special deep-water devices and instruments. The problem of investigation of the BBL was raised rather long ago (Wimbush and Munk, 1970; Eittreim et al., 1975; Armi and Millard, 1976; Smith and McLean, 1977; Weatherly and Martin, 1978), but it began to receive serious attention only after HEBBLE Program (Hollister et al.,1980; Koening, et al., 1983; McCave, 1983; Nowell et al., 1983; Weatherly and Kelly, 1985; Grant et al., 1985). This increase in interest resulted primarily from practical concerns including the extraction of minerals from the sea flor, anti submarine defence, navigation, selection of waste burial sites, protection of underwater installations and the like.The BBL of the ocean is extremely interesting with respect to hydropysical phenomena, yet it has not been well studied. Occasionally there are dramatic velocity increases in the benthic current, the so called "benthic storms" (Hollister and McCave, 1984; Weatherly and Kelly, 1985; Klein, 1987; Gross et al, 1988; Kontar and Soloviev, 1989; Richardson et al., 1993; Kontar and Sokov, 1994).Synoptic eddies above the area studied are supposed to be the cause of the observed events. In our presentation we suggest that additional mechanisms are needed to explain some observations of benthic storms.

EDDY FORMATION BY DENSE FLOWS ON SLOPES IN A ROTATING FLUID

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P.G. Baines (Division of Atmospheric Research, CSIRO, PB1, Mordialloc, Victoria 3195, Australia.)

The flow generated by a continuous source of dense fluid on a slope in a rotating system is investigated by making laboratory experiments. The dense fluid initially flows down the slope but turns (under the influence of rotation) to flow along the slope. However, some of the dense fluid drains downslope in a viscous Ekman layer. In some cases the Ekman layer becomes unstable to growing waves. The initial downslope flow of the dense current takes the ambient upper layer fluid out into deeper water, thus stretching columns of ambient fluid. If there is sufficient stretching, and provided that the viscous draining is not too strong, cyclonic vortices form in the upper layer and the dense flow breaks up into a series of domes. The strength of the upper layer cyclones depends on the relative amount of stretching, reaching approximately $2f$ in the experiments presented here. The frequency at which the eddy/dome structures are produced also depends on the stretching, while the speed of the structures as they propagate along the slope is influenced by viscous effects. The flow of dense fluid on slopes is a very important part of the global ocean circulation system and the implications of the laboratory experiments for oceanographic flows are discussed.

EDDY TRANSPORTS IN THE NORTHEASTERN NORTH ATLANTIC

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Eddies transport heat, momentum and potential vorticity, and so are therefore responsible for an irreversible movement of properties and mass without needing a mean flow. To investigate their role in the NE North Atlantic the SeaSoar and ADCP data from the 1991 "Vivaldi" cruise were used. These data cover an area of 1700km × 1500km between 39°N and 54°N and 35°W and 15°W. To maximise statistical significance, but retain the possibility of determining north-south gradients, statistics of eddy quantities were calculated separately for the northern and southern halves of the area. The mean flow in the south is essentially zero; the north is dominated by the North Atlantic Current (NAC). The eddy kinetic energy in the south is however only about 20% less than in the north. The eddy momentum transports, or Reynolds stresses, [u'v'], show a negative northward gradient, corresponding to an acceleration of the mean eastward flow associated with the NAC. This gradient decreases with depth. The eddy heat transports, [u'T'], are small in the south but show a clear poleward transport in the north. The eddy potential vorticity fluxes, [u'q'], show eastward zonal transport in both north and south. The meridional transports show a convergence. The residual or rectified eddy transport velocity implied by the eddy potential vorticity flux, $u^* = -[u'q']/[q]$, is in the SW quadrant in the south, while in the north it is in the NW quadrant. The speeds are of order 1 cm/s and the directions correspond to a divergence from the formation region of the Eastern North Atlantic Central Water.

AN ADAPTIVE REMESHING FINITE ELEMENT SEMI-LAGRANGIAN BAROTROPIC OCEAN MODEL

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We present a new model combining for the first time in ocean modelling the finite element and semi-Lagrangian methods on unstructured meshes. A barotropic two dimensional flow is simulated by discretizing the inviscid shallow water equations. We show that most of the known combinations of finite elements for velocity and sea level variables give rise to severe oscillations on unstructured meshes. The worst results are obtained with the most popular combination. A new element pair which leads to good results is presented. Linear gravity wave experiments are performed to validate the discretization scheme. Analytical and numerical results compare well. The trajectory of a typical oceanic eddy is then examined using the unforced non-linear inviscid equations. We show that an unsmoothed discrete boundary has a crucial impact on the results, and can generate spurious eddies. The flexibility of the finite element discretization is thus a major advantage. The treatment of advection terms is at least fourth order accurate by using a kriging scheme. This leads to a high accuracy of slow Rossby modes on unstructured meshes. An adaptive mesh is also used to improve efficiency of the model. Finally, different experiments are performed using a prescribed wind stress and bathymetry.

THE ROLE OF CONVECTIVELY FORMED GIN-SEA-INTERMEDIATE WATER FOR THE DENMARK-STRAIT OVERFLOW

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The role of deep convection for the circulation of the GIN-Sea with main emphasis on the Denmark-Strait Overflow water masses is examined by means of a numerical coupled ice-ocean model (Hamburg Ocean Primitive Equation Model). Model runs with different thermal forcing and with different parametrization of deep convection were performed to provide model scenarios with different production rate of intermediate water.

The model results support the new circulation scheme of Maurizen (Deep Sea Research, 1996). According to this scheme, mainly two dense water masses — The Arctic Atlantic Water (AAW) and the Return Atlantic Water (RAW) — supply the Denmark-Strait Overflow. Both water masses are formed when Atlantic Water (AW) in the Norwegian Atlantic Current becomes gradually denser by atmospheric heat loss, subducts underpolar water, mixes and gets on different paths through the Nordic Sea to the East Greenland Current.

Furthermore, the model results show that through the convectively formed Greenland Sea Intermediate Water (GSIW) does not contribute to the Denmark-Strait Overflow itself, its production rate influences the composition of Denmark-Strait Overflow Water, in particular the RAW. Changes in the production rate of the GSIW influence the temperature and salinity (not the currents!) in the Denmark-Strait, already after half a year.

SEASONAL INTERBASIN FRESH WATER EXCHANGE IN THE SOUTHERN OCEAN FROM BALANCE POSITIONS.

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The work is addressed to the problem of annual cycle in fresh water interbasin exchage in the Southern Ocean. Fresh water balances of the Atlantic, Pacific and Indian oceans are considered to determine the divergences of fresh water fluxes (in Stommel's interpretation) for each basin. Evaporation and precipitation data were taken from NCEP/NCAR reanalysis (1996 issue), run-off data were from combining [Baumgartner, Reichel, 1975.] and [The World Water Balance and Water Resources, 1974]. NODC-94 data set was used to calculate annual changes in fresh water content for all basins. These allowed us to build up a full system for interbasin fresh water fluxes on each basin border of the Southern Ocean from balance positions. Intercomparisons with independant estimations are considered. Balance method seems to overestimate real fluxes, mainly because of storage changes component in fresh water balance of the oceans.

ROTATING GRAVITY CURRENT AND CHANNEL FLOWS

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The results of a laboratory investigation of rotating gravity currents at length scales of the order of a Rossby radius and time scales of the order of a rotation period are presented. The study is applicable to buoyancy driven flows through straits, mid-ocean ridge valleys and fracture zones, and intermittent gravity currents (e.g. Kyucho). The experimental apparatus consists of a rectangular tank mounted on a rotating table. The results are compared with theoretical models (e.g. Hacker, 1996) for flows generated by full-depth locks (and thus currents that occupy a significant proportion of the channel depth). The effect of varying the fractional depth is examined, both in the laboratory and by extending the theory. For weakly rotating currents, $w/R \leq 1$ (where w is the tank width and R the Rossby radius), the measured current speed is in agreement with the theory. At higher rotation rates, $w/R \approx 2$ and more, the speed is lower than anticipated and significant vertical mixing is observed. It is conjectured that this mixing is the cause of the divergence from the theory. Experiments where the effect of varying the fractional depth of the current is examined indicate that, for $0 < w/R < 1$, the speed is approximately inversely proportional to the fractional depth. For higher rotation rates no relationship is apparent.

SUBPOLAR GYRE CIRCULATION: HIGHLIGHTS OF A FALL 1996 SURVEY FROM *R/V KNORR*

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The *R/V Knorr* conducted a hydrographic survey of the central and eastern subpolar gyre comprised of a 60 station section from the Azores to Cape Farewell, a 70 station section from Angmagssalik to Ireland, and 59 stations south of Rockall Bank and west of Porcupine Bank and the Goban Spur. We discuss:

- The flow of thermocline waters from the central and eastern subtropical gyre into the eastern subpolar gyre around the Rockall Plateau complex, and their subsequent evolution westward to the Irminger Basin, including their deflection by the Reykjanes Ridge and confluence into the East Greenland Current.
- The spreading of newly ventilated Labrador Sea Water into the Irminger Basin and its conveyance by the branches of the North Atlantic Current into the Iceland Basin and the Rockall Trough and its interactions with Mediterranean Water and Nordic Seas Overflow Waters.
- The elements comprising the Deep Northern Boundary Current from its origins south of the Rockall Plateau, including high resolution crossings south and west of the Plateau, both sides of the Reykjanes Ridge, the Charlie-Gibbs Fracture Zone and the continental slope off East Greenland.

DENSE WATER FORMATION IN STORFJORDEN

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Abstract. Storfjorden in the western Barents Sea is an area with favorouble conditions for the formation of dense shelf water by brine release from high ice production. Making use of the comparability of ice cover, hydrographic and meteorological data the formation and its interannual variablity are investigated in a one-dimensional model. Parametrizations of thermodynamic ice production, frazil ice collection, ridging and export are combined to determine time series of mean ice concentration and ice production for Storfjorden during six subsequent winters. A sensitivity study shows that these processes interact in such way that the response of ice production to meteorological variablity is reduced. Therefor, the uncertainty of ±50-70% of ice production estimates given from satellite and meteorological data can be reduced to ±30-40% by application of the model. The input to the ice model are data from a near meteorological station, the output a time series of mean ice production. The corresponding salt flux and a model of hydraulic control for the outflow of formed dense waters are used to estimate the outflows' properties and amount in agreement with hydrographic observations from 6 subsequent years and current measurements from one winter. The estimated mean contribution of Storfjorden to the deep waters of the Arctic Seas is 0.12±0.03 [Sv] with a high interannual variablity and extreme values of 0 and 0.3 [Sv]. Compared to present estimates of deep water renewal in the Arctic Ocean System Storfjorden would produce 10-20% of these waters.

Water mass transformations in the Romanche Fracture Zone

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The Romanche Fracture Zone is a pathway for the Lower North Atlantic Deep Water and the Antarctic Bottom Water from the western to the eastern troughs of the equatorial Atlantic Ocean, across the Mid-Atlantic Ridge. A series of cruises, which have recently visited the Romanche Fracture Zone, allow to present a detailed description of the mutual mixing of the Lower North Atlantic Deep Water and the Antarctic Bottom Water as they flow eastward through the fracture zone. The quantification of vertical mixing coefficients is attempted both from hydrographic profiles using the Thorpe scales and from a heat budget constructed downstream of a current meter array. The mixing coefficients that are estimated are two to three orders of magnitude larger than those found in abyssal plains.

SPACE TIME SCALES OF TIDAL INTERNAL WAVES IN THE SARGASSO SEA

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Tidal internal waves were studied using the measurements of velocity and temperature from moored buoys in the Sargasso Sea during long term experiments POLYMODE and ARRAY. The study area was located far from continental slopes and Mid-Atlantic Ridge which are the source areas for these internal waves, thus the energy level is close to the backgroud one. Unlike areas where tidal internal waves have a stable character as it is near submarine ridges, the features of the observed oscillations vary in space and time, yet their spectral density is greater than the backgroud level given by the GM model. The properties of tidal internal waves are strongly affected by intensive eddies which change the initial tidal frequency of the oscillations in accordance with the Doppler effect caused by intensive currents.

DEEP WATER GENERATION OF TIDAL INTERNAL WAVES IN THE CABO VERDE BASIN OF THE ATLANTIC OCEAN

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Results of modeling of generation of tidal internal waves over rough bottom topography in the Cabo Verde Basin are compared with field mesurements during Polygon-70 experiment with 17 buoy stations and Mesopolygon-85 experiment (70 buoys). Tidal internal waves are generated when currents of the barotropic tide flowing over uneven features of the bottom obtain vertical components. The bottom in the Cabo Verde Basin is covered with hills 500 - 1000 m high located at a distance of 10 or 20 miles from each other. The interection of tide with corrugated bottom topography induces internal wave motion. Due to the fact that the waves are observed right over the source of their generation, a multimodal structure is observed. Other parameters of internal vaves are obtained from measurements which are in a good agreement with the results of numerical modeling.

THE PENETRATION OF ANTARCTIC BOTTOM WATER INTO THE SOUTH ATLANTIC

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Results are presented from an Ocean General Circulation Model which was used to examine the pathways of Antarctic Bottom Water in the South Atlantic Ocean. The model is based on the code of Bryan-Semtner-Cox. The model has open boundaries to the North, at the Drake Passage and between the southern tip of Africa and Antarctica with conditions on the stream function, temperature and salinity at the open boundaries derived from the Fine-Resolution Antarctic Model. The forcing at the sea surface is derived from the Levitus (1994) and Hellermann-Rosenstein (1983) wind stress climatologies. Heat and mass fluxes in this limited area model agree well with previous estimates. The model includes passive tracers to track the presence of the AABW. The flow of these tracers is compared with chemical tracers measured during WOCE cruises A23 and A11. The model tests whether AABW can pass through channels in the complex Scotia Sea region or whether it must pass to the East as has been suggested by Smythe-Wright and Boswell (1995) on the basis of CFC tracer data. The trajectories of the AABW in the South Atlantic, and the flux of heat, mass and freshwater it carries northwards, are also investigated.

DIAGNOSTIC MODELLING WITH JEBAR: APPLICATIONS TO THE NORTH ATLANTIC

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A diagnostic, finite element, barotropic ocean model has been used to simulate the mean circulation in the North Atlantic and North Pacific. A key feature in obtaining realistic solutions is the inclusion of the joint effect of baroclinicity and relief (JEBAR). Comparisons of the bottom pressure torque, which dominate the solution in the diagnostic model, with that found in some OGCMs reveal that some of the deficiencies in transport and gyre structure in these models may be associated with a gross underprediction of this term. Intercomparisons between the simple diagnostic model and the full OGCMs show that errors in the density field in the subpolar gyre may be important.

RECONSTRUCTION OF STEADY STATE CIRCULATION IN THE ROSS SEA USING VARIATIONAL APPROACH.

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The Southern Ocean hydrography, austral summer Hellermann wind stress, TOPEX/POSEIDON surface elevation data and WOCE S4-section data were assimilated in a steady state non-linear numerical model using variational method. The thickness of the Ross Ice Shelf (RIS) was taken into account with a help of a weak constraint zero-transport condition along its ridge. The main feature of obtained circulation is the Ross Sea Gyre with a transport about 8 Sv and typical velocities near 0.7 cm/sec. The most part of boundary along RIS ridge is characterised by inflow with transport about 1.5 Sv, which gives 5.5 years ventilation time scale. Up to 5 cm/sec outflow concentrates in the western part of RIS ridge and then forms along Pennela coast western current with transport near 2 Sv. Average Ekman upwelling rate in the major part of the basin amounts to 22 m/year. Downwelling in the shelf regions is estimated as 300 m/year.

DYNAMICS OF NORTH ATLANTIC MODELS (DYNAMO): VENTILATION OF THE SUBTROPICAL GYRE

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and the Dynamo Group.

The European MAST-II DYNAMO project aims at an improved simulation of the circulation in the North Atlantic Ocean by comparing three eddy-resolving models with different formulations for their vertical coordinate (using fixed horizontal levels, isopycnic layers, and terrain-following coordinates). The models are forced by ECMWF fluxes and have been set up to be as nearly similar as possible. Each model has completed a 15-year spin-up integration, followed by a 5-year intercomparison experiment. We will describe the ventilation of the subtropical gyres in the three models, primarily by investigating the patterns of potential vorticity on density surfaces, which can be used as a dynamic tracer. The relationship between the ventilation patterns and the presence or absence of certain current features in the central regions of the gyres (which in the isopycnic model resemble an Acores Current in the Eastern basin) will be discussed. Comparisons will be made with observations in order to assess the realism of the results from the respective models.

WATERMASS TRANSFORMATION IN THE SURFACE OCEANIC BOUNDARY LAYER

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Recent work with large scale ocean models has suggested the importance of mixing within and at the base of the surface ocean boundary layer (OBL) in mediating the transformation of water masses by surface fluxes. Here we compare results from mixed layer models with time series of observations from ocean weather ships to estimate the relative importance of OBL mixing and surface fluxes in determining the watermasses produced. In some areas we find that mixing almost completely balances the surface fluxes, whereas in others, such as near the Gulf Stream, the surface fluxes dominate. OBL mixing is found to be particularly important for salinity and temperature treated separately. We then present scaling arguments to estimate the global significance of this OBL mixing.

THE EFFECT OF COCCOLITHOPHORE BLOOMS UPON THE THERMAL STRUCTURE OF THE SPRING MIXED-LAYER

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Coccolithophores scatter light strongly. Here we study the effects which a occolithophore bloom has upon the spring warming of the mixed layer. We use a mixed layer model together with net downwelling irradiance profiles calculated with a full model of light absorption and scattering. The bloom increases the ocean albedo and so leads to a reduced heat input to the ocean, but also reduces the depth penetration of the solar radiation and so gives relatively more surface warming. We present results both from simple idealised spring scenarios, and from a simulation of the 1991 Marine Light in the Mixed Layer experiment.

The OMEGA Project: Observations and Modelling of Eddy Scale Geostrophic and Ageostrophic Circulation.

The OMEGA group: Dept. Fisica, Universitat de les Illes Balears, Spain; Southampton Oceanography Center, UK; Institut de Ciències del Mar (CSIC), Spain; GHER, Université de Liège, Belgium; Universita di Pisa, Italia; Dept. de Ecología, Universidad de Málaga, Spain; CNRS/LODYC, France.

The OMEGA project is an interdisciplinary physically based initiative aimed to (1) determine the spatial and temporal variability of the three dimensional ageostrophic circulation in upper ocean fronts (2) understand the relationship between biological variability and mesoscale physics, and (3) provide the scientific community with a new and useful tool for computation of vertical velocity from routine CTD and ADCP data. The field studies were completed during October (BIO Hespérides) and December (R/V Discovery) 1996. Data obtained in 4 consecutive samplings of the same area included Seasoar, ADCP, fluorescence, acoustic backscatter, nutrients, flow-cytometry, lagrangian floats, etc. Preliminary analysis of these data show the existence of significant variability at scales of the order of the internal Rossby Radius and also indirect evidences of vertical motions. The data will be analyzed and used to compute the associated three-dimensional circulation using methods and models of different complexity, such as quasigeostrophic (QG), semi-geostrophic (SG), and iterated geostrophic (IG). These results will be compared to the diagnostic results obtained from the digital filter initialization of a primitive equation model using the different observed fields to specify the initial conditions. All these computations will be also compared to the lagrangian observations.

THE SPREADING OF LABRADOR SEA WATER IN THE EASTERN NORTH ATLANTIC

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The spreading of Labador Sea Water (LSW) in the eastern North Atlantic south of 55°N is described on the basis of a set of recent, high resolution hydrographic lines and using an inverse model of that basin general circulation. An isopycnic "salinity anomaly" (ΔS) relative to a standard θ/S curve is used as a tracer to detect the main branches and limits of dominant influence of the intermediate water masses. The low salinity LSW is seen crossing the Mid-Atlantic Ridge at latitudes around 50°N and different pathways of eastward and southward recirculation are described. A marked front exists around 1800m between LSW and the more saline Deep Mediterranean Water (DMW) in the latitude range 40°N-45°N. The inverse model velocity field confirms most of the features deduced from the tracer distributions and allows to estimate basic transports of LSW. It also suggests DMW to be former LSW that, while flowing southward, has acquired a higher salinity through vertical mixing with the Mediterranean Outflow Water above. A simple scaling confirms that double diffusion could build the strong thermohaline front between LSW and DMW. Several mesoscale structures of anomalously high LSW influence are present in the dataset south of the LSW-DMW front, an example of which is provided by the trajectory of a RAFOS float from the SEMAPHORE experiment. The velocity and potential vorticity fields suggest that these "LSW-eddies" are formed by baroclinic instability of the LSW/DMW front.

THE VORTICITY BALANCE IN THE NORTHEASTERN ATLANTIC, FROM THE OUTPUTS OF A REGIONAL MODEL WITH REALISTIC BATHYMETRY AND FORCING

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A coarse resolution PE model of the northeast Atlantic has been implemented. The circulation is forced by ECMWF monthly surface fluxes, and seasonal tracer fields at the lateral open boundaries, along which the local depth-integrated flow is not constrained: the barotropic streamfunction thus only depends upon the interior dynamics, and the model determines the fluxes across the boundaries by itself.
The results of the simulation are used to compute the terms of the depth-integrated vorticity equation : $\beta\overline{v} - \frac{f}{H}\overline{u}.\nabla H + J(\psi, \frac{\nabla^2\psi}{H}) = f\frac{\partial w}{\partial z} + J(\Phi, \frac{1}{H})$. Within the weakly nonlinear regime simulated by the model, this analysis shows how the barotropic circulation depends upon the geography of the basin, and evaluates the contribution of the external forcing.
This study is followed by high resolution ($\sim 12km$) simulations in order to understand the respective influences of the baroclinic instability and of the wind fluctuations onto the generation of mesoscale activity in the basin.

SEASONAL AND INTERANNUAL VARIATION OF THE CTD-DERIVED WATER MASS CENSUS IN THE SOUTHERN GIN SEA REGION

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The temporal and spatial variabilities of the watermasses in the Iceland-Faroe frontal and southern Norwegian Sea region are investigated. The study utilized CTD observations from 7 cruises in the 1986-1993 period. The watermass census is computed using the class definitions of Swift and Aagaard (1981)+ and Read and Pollard (1992)*.
In the region 9W-10E, 65N-69N of the Norwegian Sea, Atlantic Water (AW) was present at about 24%, Lower Arctic Intermediate Water (LAIW) at about 12%, Norwegian Sea Deep Water (NSDW) at about 33%, and Greenland Sea Deep Water (GSDW) at about 19%. There was also a DW class present with ($-.5 < T < 0$, $34.85 < S < 34.92$) at about 9%. The amount of Arctic Surface Water (ASW) was less than 1 %, and Upper Arctic Intermediate Water (UAIW) less than 2%.

+ Deep-Sea Res. 28A, pp.1107-1129, 1981.
* J. of Phys. Ocean. 22, pp.1365-1378, 1992.

EXPERIMENTAL STUDY OF MEDDY'S DIPOLE LENS FORMATION NEAR MOROCCO CONTINENTAL SLOPE

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Data of three CTD-surveys during july 6-28 1988 conducted by r/v "Vityaz" near Gibraltar area and Morocco coast are analyzed. Successive increase of mediterranean water inflow (salinity above 36.5 psu and temperature above 12 deg C) in form a jet in the region located more than 250 km from Portuguese continental slope to the 700-1300 m depth as traced leads to formation of an asymmetric dipole lens: anticyclonic (western) and cyclonic. Currents meters on moored buoy station set in the area of inflow jet registered velocities up to 0.4 m/s directed SSW and confirmed the change of rotation sign between the lens cores. Geostrophic circulation calculated using the data of survey confirmed the evidence of Meddy's dipole structure. This work is supported by RFBR grant N 96-05-65287.

INTERGRATION OF THREE-DIMENSIONAL MOTION EQUATION FOR COMPUTATION OCEAN CIRCULATION.

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To simulate water circulation in the sea with variable depth by intermediate definition intergral stream functions or surface elevations from the elliptic equations is in a difficulty through choosing boundary conditions and numerical solution for the nonuniform relief bottom.
In this study to offer using primitive equations, for which the boundary conditions have been simplied. For computation of currents in a large time-space spectrum from a laboratories experiment imitation to general ocean circulation, it is more suitable to use this mathematical model due to its universial quality and simple algorithm.
The equation for calculating surface elevations is determined from equation of continuity, where the kinematical condition at the sea-surface and condition for vertical component of current velocity at upper part boundary-layer bottom are use.
The sequence of operations can be formulated in two steps. First diagnosis problem is to be calculated until going out of steady kinematical energy. Then the prognosis problem with attracting equations of warmth and salt diffusion is realised, where the first conditions for last step are determined by resulting of diagnosis one.
Implementation of this model was made by means of a three-dimensional circulation developed for South-Chine sea and the Baltic sea. The obtaining currens scheme was showed less smoothing than the result of simulation with using the intergral stream function.

THE MEDDY IDENTIFICATION IN NE-ATLANTIC ACCORDING THE REGION OF FORMATION USING THE SOUND DISPERSIVE LAYERS POSITION

Plakhin Eu.A., Aleynik D.L. (P.P.Shirshov Institute of Oceanology, 23, Krasikova, 117218, Moscow, Russia)

Different mechanisms of Meddy formation in the Gulf of Cadix determine their characteristics in the Canary Basin. In particular, The Meddy formed in the canyon area of Gulf of Cadix contain the mineral and organic particles that can be registrated by acoustic methods and thus be indirectly indicate the site of their formation. This work is supported by RFBR grant N 96-05-65287.

CONVECTION IN THE GREENLAND SEA: PLUMES AND CHIMNEYS

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J. Backhaus

One of the most important areas for convection and renewal of deep water is the Greenland Sea. Here on average 16.000 km^3 of deep and intermediate waters are formed during the winter period, providing one source for the overflow into the North Atlantic. The link between the convection itself and the large-scale circulation follows a cascade of processes on different spatial and temporal scales. Convection is intermittent and the sinking plumes are only a few hundred metres wide and have a life time of a few hours. The combined action of many plumes, under the influence of the earth's rotation, form meso-scale eddies of several kilometres width. Many of these again form the pool of newly formed water of the Greenland Sea gyre. We will discuss this chain of scales leading from convection to the global ocean circulation, using observations made during several cruises of RV VALDIVIA in the Greenland Sea during winter. In addition results from numerical simulation studies made with a non-hydrostatic coupled ice-ocean model are presented.

FORMATION OF NADW AND ITS CFC-12 – SIGNAL IN A 70-YEAR INTEGRATION OF A HIGH RESOLUTION NORTH ATLANTIC MODEL

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Simulation of the uptake and redistribution of anthropogenic chloroflourocarbons (CFC) represents a powerfull tool to diagnose the mechanisms of watermass formation and spreading in ocean circulation models. In the present study we use dissolved CFC-12 as a tracer to analyse the renewal of North Atlantic Deep Water (NADW) in the high resolution ($\frac{1}{3}^\circ \times \frac{2}{5}^\circ$) CME model of the North and Equatorial Atlantic, with focus on the role of the wintertime deep convective mixing in the Labrador Sea and overflow from the Nordic Sea. Previous model experiments had shown that the convection (to depths of about 2000m) in the Labrador Sea has a negligible impact, compared to the effect of the overflows from the nordic seas, on the deep water formation rate and the meridional overturning. It represents, however, an effective conduit for the downward penetration of surface water saturated with atmospheric tracer gases. We will present results of a long-time model integration to discuss the physical processes determining the temporal evolution of the 3-d CFC distribution in the deep ocean, in particular the role of deep winter convection and overflow for the CFC-uptake in the subpolar North Atlantic, and the southward transport of CFC-enriched water with the Deep Western Boundary Current.

DEEP AND INTERMEDIATE WATER CIRCULATION IN THE SUBPOLAR NORTH ATLANTIC

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The subpolar North Atlantic is the region, where the water masses of the North Atlantic Deep Water (NADW) are formed and modified. The onset of intense deep convection in mid 1980s in the Labrador Sea led to substantial changes in the thermohaline characteristic as well as in the tracer signal of the intermediate water masses throughout the subpolar North Atlantic. The arrival of these new LSW vintages in other parts of the ocean is marked by a cooling, deepening and densification of the local LSW core. The tracer (chlorofluorocarbons, components CFC11 and CFC12) distributions allow more insight in the time scales and possible spreading paths of the NADW components. Newly formed Labrador Sea Water (LSW) needs about 6-8 months to invade the Irminger Sea. The upper time limit for LSW to reach the entrance of the Rockall Trough in the Northeast Atlantic is estimated to 7 – 9 years.

THE EFFECT OF EDDIES ON THE VENTILATION OF SUBTROPICAL GYRES

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The ventilation of the thermocline waters of subtropical gyres controls the transfer of properties set by air/sea exchange into the ocean interior. Here we investigate the role mesoscale eddies play in this transfer. Eddies can affect ventilation rates in two ways; through eddy transport across the surface defined by the depth of the wintertime mixed layer and by shaping the Eularian mean circulation in relation to the outcropping of isopycnic surfaces. We use an isopycnic coordinate ocean circulation model configured for the North Atlantic in both a non-eddy resolving and eddy resolving mode.

Most of the experiments have been undertaken with the non–eddy resolving model where eddy transports are parametrized by a thickness diffusion (similar to the Gent and McWilliams scheme for level models). Emphasis has been placed on the sensitivity of the circulation and ventilation rate to vertical resolution and the value and spatial variation of the thickness diffusion coefficient. An order of magnitude change in this coefficient produces a 40–70% decrease in the ventilation rate. Most of this decrease is because of the change in the Eulerian mean circulation. The contribution of the eddy transport varies between 10-50% with the eddy contribution being negative for a small thickness diffusion coefficient and positive for large. The results from the eddy–resolving run will be used to test these conclusions and various parametrization schemes of eddy tracer transport.

A DENSE BOTTOM WATER PLUME IN THE WESTERN BARENTS SEA

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Ventilation of the central Arctic Ocean is mainly a result of slope convection of cold, brine-enriched waters from the shelf seas. Divergence of sea ice caused by off-shore winds and strong tides makes near-shore areas favourable for the production of dense water through cooling and brine release related to the generation of sea ice. From the generation area, the dense water spreads towards the shelf edge, mixing with ambient water and thereby changing its thermohaline signature significantly. The entrainment of ambient water ultimately determines the depth range which shelf water is able to ventilate in the central Arctic Ocean. The Storfjord in the Svalbard Archipelago was chosen to study the generation, spreading and mixing of dense shelf water. From August 1993 to September 1994, four moorings were deployed south of Svalbard. Current meters, thermistor chains and CTDs measured the strength and properties of both the bottom water plume created in the Storfjord and the modified plume 130 km downstream at the western shelf edge.Cold bottom water, with temperatures close to the freezing point, drained from Storfjord continuously from March until at least September with a mean speed of 0.14 m/s. One month after leaving the Storfjord, the plume reached the shelf edge where it had higher temperatures, slightly lower salinities and was spread out over a larger horizontal extent. This poster discusses in detail the modification of the plume during its transit across the shelf.

HYDROGRAPHIC OBSERVATIONS IN THE EASTERN ARCTIC DURING ACSYS 96

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From July to September 1996, RV Polarstern carried out hydrographic sections in the eastern Arctic (ACSYS 96). The aim was to study the large-scale circulation with special emphasis on the flow of waters of Atlantic origin. Atlantic water, providing the main oceanic heat and salt source for the Arctic Ocean, enters the Arctic Ocean through the shallow Barents Sea and through the Fram Strait. Both branches merge north of the Kara Sea and circulate cyclonically through the Eurasian basins. A part of the flow enters the Canadian Basin. During ACSYS 96 a section with CTD-measurements and a comprehensive set of tracers (Oxygen, nutrients, the Carbon system, CFCs, Helium/Tritium, O-18) was occupied for the first time across the St. Anna and the Voronin troughs to identify the properties of the Barents Sea branch of Atlantic water at its entrance to the Arctic Ocean. A transect with closely-spaced stations reaching from the north-eastern Kara Sea, across the Nansen and Amundsen basins and into the Makarov Basin resolved the confluence of the two branches and traced the return flow in the various basins. The observations are generally consistent with recently published conceptual mean circulation schemes. Evidence was found for eddies transporting water from remote sources into the central basins.

GLACIAL AND MELTWATER OCEAN THERMOHALINE CONVEYOR

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The glacial–to–interglacial changes of the global ocean thermohaline conveyor is addressed with the emphasis on its North Atlantic (NA) branch. Both the regional and the global simulations have been carried out to evaluate a local versus a remote effect of a meltwater discharge in the Nordic Seas and NA. The Holocene/Modern (HM), the Last Glacial Maximum (LGM), and the Meltwater Event (MWE) near 13,500 ^{14}C years B.P. are simulated on the basis of the CLIMAP sea surface temperatures that are updated in the Nordic Seas and in the northern NA by data processed at the GPI (Kiel), using sea surface salinities from different data sources (compiled at GPI, Kiel) and winds from the ECHAM atmospheric model (Lorenz et al., 1996). Both global and regional simulations show a substantial weakening of the NA forward glacial conveyor belt. Much weaker deep western boundary current is found during the LGM and MWE. During MWE the disappearance of the NA forward conveyor is accompanied by a much enhanced AABW incursion. During the LGM, the deep NA ocean was still ventilated, though less than at the HM, whereas it was less ventilated than the Southern Ocean during the MWE. The global ocean circulation model shows that the collapse of the forward conveyor and reversing of the deep conveyor is a global rather than regional response to the northern NA freshening.

MODELLING THE EFFECT OF THE WEDDELL SEA TIDES ON THE FILCHNER-RONNE ICE SHELF

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The most important source of bottom water in the Southern Ocean is thought to be the Weddell Sea, accounting for about 80% of total production, and water modified by passage under the Filchner-Ronne Ice Shelf (FRIS) is a major constituent. Thus the Antarctic ice shelves, in particular FRIS, could have an important influence on the global ocean and are therefore important when considering the world's climate.
An earlier study, using a finite-difference numerical tide model, has shown that a simple increase in the bottom friction coefficient in the ice-covered region, in order to simulate the effect of FRIS, is inadequate to describe the movement of the ice shelf at sites approaching the grounding line. Indeed, to reproduce the observations at these sites it was necessary to use unrealistically high values of friction and consequently agreement with sites nearer to the ice front was lost. It was suggested that a friction coefficient which matched the open-ocean value at the ice front and increased as some function of distance as the grounding line was approached might enable the model to reproduce the observations more consistently over the entire model domain.
As a precursor to modifying the tide model to include a varying friction coefficient, an elastic beam model of ice-shelf flexure has been investigated. Results indicate that the ice shelf would move elastically with the tide except in a region within a few kilometres from the grounding line where the movement is suppressed. One assumption of the model is that the ice shelf is of constant thickness and this may be one reason for its inability to explain the observations at ice-shelf sites away from the grounding line.

To the Question of Water Mass Formation

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Temperature and salinity extrema in the ocean interior may occur simultaneously (Mediterranian outflow in Atlantic) or separatly (temperature minimum and maximum in subarctic, salinity maxima and minima in subtropics). The water mass conception and transformation notion give an verisimilar but not clear and single answer about the reasons of differences of the origin of these extrema. In particular, it may be seen on the robustness of formation of so called North Pacific Intermediate Water. The alternative point of view on the problem consists of the idea that extrema in vertical temperature and salinity distribution have to be examined not as a substance but as temporal phenomenon. In this way the question of water mass transformation could be replaced by the question of separate temporal variability of temperature and salinity fields. As well known, temperature and salinity are directly influenced by atmosphere-ocean interaction processes. Both of them change simultaneously but separatly of each other because temperature depends on heat budget and salinity is defined by fresh water balance. Temporal variability of heat and fresh water balances in different time scales (from synoptical to climatic) is the main reason of appearance and disappearance of temperature extrema in subarctic and salinity extrema in subtropics in corresponding time scales. That is why there are multiformity of different time scales temperature and salinity extrema in the ocean interior. The properties of the extrema depend on the values of balances but not on gorizontal advection.

PRELIMINARY RESULTS FROM THE ARCANE FLOAT EXPERIMENT

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The ARCANE experiment is designed to measure the northward penetration of Mediterranean Water in the eastern North Atlantic Ocean. It is comprised of two components. The major thrust is the observation of flow near the eastern boundary at intergyre latitudes (40-50 N) by eulerian and lagrangian methods. A secondary effort is aimed at observing the general circulation in a limited interior region of the eastern Atlantic, and its interaction with the boundary flow over this latitude range. First results of the interior flow study are reported here, from six months of float data at 1000m nominal depth. A companion project, EUROFLOAT, also has float measurements at this level in the same time frame, but farther south. Measurements to the north during the same period will take place in the context of the WOCE/ACCE program.

A GENERAL PRESSURE GRADIENT FORMULATION AND ITS APPLICATIONS TO NORTH ATLANTIC MODELING

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A new formulation of the pressure gradient force for use in models with topography-following coordinates is proposed. It is based on a Jacobian formulation, it can be used in conjunction with any vertical coordinate system, and it is easily implemented. Two discrete schemes are derived: the first using standard centered differencing in the computational vertical coordinates and the second using vertical weighting such that the hydrostatic inconsistence is eliminated for density perturbation fields which vary quadratically. Both schemes achieve second order accuracy for any vertical coordinate and are significantly more accurate than the conventional scheme based on pressure differences.

The new schemes are numerically consistent, energetically consistent and accurately represent the bottom pressure torque. Their performances in a real ocean model are tested prognostically for both numerical accuracy and long-term integral stability, based on simulations for a large-scale wind-driven basin with and without topography. The integrations are carried out for 10 years in each case. An application of the model to the study of deep water formation in the high latitude North Atlantic will be discussed.

MESOSCALE VARIABILITY IN DENMARK STRAIT

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The outflow through Denmark Strait shows remarkable mesoscale variability that appears to be characterized by the continuous formation of intense mesoscale cyclonic eddies just south of the sill west of Iceland. Our hypothesis is that these cyclones are formed by stretching of the mid-level water (Arctic Intermediate Water) that outflows through Denmark Strait. The main test of this new hypothesis is by way of numerical experiments carried out with an isopycnal coordinate ocean model. An outflow is produced by imposing buoyancy forcing over a marginal sea. If the buoyancy forcing is such as to produce both a mid-level outflow and a deep overflow, then the outflow is strongly time-dependent, developing intense mid-level cyclones just south of the sill where the dense overflow water begins to descend the continental slope. Numerical experiments show that the essential ingredients for the development of strong eddies are: 1) a continuous outflow of mid-level water having an anomalous potential vorticity relative to the open ocean (high potential vorticity for cyclonic eddies) and 2) a deep overflow that descends the sloping bottom. Given the dynamics of the cyclogenesis, it is probably better described as an adjustment process rather than as an instability of the overflow current. The characteristics of the eddies (frequency, scale, vertical structure, kinetic energy) are dependent on the bottom slope and stratification through constraints provided by the topographic Rossby wave dispersion relation and the total mass flux in the upper overflow.

WATER MASS FORMATION IN THE SOUTHERN OCEAN

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Water mass formation rates have been calculated from several air-sea exchange datasets, including model and ship-based fluxes. The results are divided into contributions from the three principal sectors of the Southern Ocean: Pacific, Indian, and Atlantic, in order to judge the relative importance of each region to the result. There are great uncertainties in the data from these regions, but the basic distribution shows a buoyancy gain at higher densities, and a buoyancy loss at lower densities, opposite to the usual form for a convecting ocean basin such as the Atlantic. However, the formation of very dense water near or over the shelf region is not resolved. These results are discussed in terms of mode water formation and the traditional simple meridional overturning model.

MEAN CIRCULATION AND TRANSPORTS IN A NUMERICAL MODEL OF THE SOUTH ATLANTIC OCEAN — COMBINING MODEL AND DRIFT DATA

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The mean circulation as derived from a low resolution (1°) general circulation model of the South Atlantic Ocean is presented. The circulation patterns agree fairly well with observations and other model results, though the model failed to reconstruct correctly characteristics on a regional scale. An example is the Brazil-Malvinas Confluence Zone which is not properly resolved by the model. To improve the modeled circulation the attempt is made, to relax the velocity field of one model layer to an observed mean velocity field which is derived from a drift data set. As a result the circulation of near-surface waters in the Subtropical Gyre is enhanced. The combination of the used data and the relaxation method seems to have only little impact on integrated quantities such as the meridional heat transport. It is shown that the modeled flow field above the themocline is influenced mainly by advective processes. Divergences in the observed data are balanced on a local scale without effectivly disturbing the large scale circulation.

A TRACER RELEASE TO STUDY THERMOHALINE CIRCULATION IN THE GREENLAND SEA.

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As part of the EU MAST-III project ESOP-2 (European Subpolar Oceans programme phase-2) a tracer release experiment was begun in the central gyre of the Greenland sea, in August 1996, at a depth of approx 350 m. The objectives of the experiment are to study (1) summer diapycnal mixing in the weakly stratified, energetic environment below the surface mixed layer, (2) the efficiency of deep winter convection in mixing the water column, and (3) how much and how quickly water from the Central Greenland sea is transported to the Denmark Strait overflow and other exits from the Northern Nordic seas. First results will be presented here. To initiate the experiment, 320 kg of sulphur hexafluoride (SF6) was released on to an isopycnal surface (sq=28.049), with a vertical accuracy of about s = 10m, in the centre of the gyre (approx 740 30N, 30W). The tracer was released in streaks in an area approx 50 square km, over a period of 10 days. Prior to the release, extensive background SF6 measurements showed a vertical plume-like structure, marking the extent of vertical mixing in the gyre over previous years. The first measurements of the added tracer were made in November/December 1996, and showed very rapid mixing in the vertical even in the summer compared to previous such studies in more quiescent areas.

CRITICAL CONTROL BY TOPOGRAPHY WITH APPLICATION TO NINE DEEP PASSAGES

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Saddle points between neighboring deep ocean basins are usually found to be the sites of unidirectional flow from one basin to the next, depending on the location of the source of bottom water. Flow in these sites appears to be critically controlled, so the interface between the bottom water and the water above adjusts itself to permit bottom water flow from the basin which contains a source of bottom water into the next. Examples in the Atlantic include flow in the Romanche Fracture Zone, the Vema Channel, the Ceara Abyssal plain, the Anagada-Jungfern passage, and the Discovery gap, but there are many more. Examples are listed for both Atlantic and Pacific oceans along with theoretical predictions of volume flux using CTD data archives. These are compared with volume flux estimates using current meters and/or geostrophic measurements for the nine best sampled cases in the ocean. Generally the agreement is within a factor of about two. Reasons for disagreement range from shortcomings of the theory to sampling problems in the data set. Future prospects are outlined.

THERMOHALINE CIRCULATION CHARACTERISTICS IN THREE HIGH-RESOLUTION MODELS OF THE NORTH ATLANTIC OCEAN

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The first systematic intercomparison of three eddy- resolving circulation models for the North Atlantic has been completed. The purpose was to study the dependence of the model circulation on the vertical discretization which was represented through geopotential levels, isopycnal layers, and topography-following coordinates, respectively. All models explicitly include the overflows over the Greenland-Iceland-Scotland ridge, and give a fairly detailed and in general realistic description of observed thermohaline circulation patterns and formation of water masses in the subpolar gyre. The principal result of the intercomparison is that the model differences are substantially smaller than typical differences between coarse-resolution models of these types, indicating that the higher resolution has achieved an important step towards a convergence of the solutions. Nevertheless, distinct differences exist in the pathways and amounts of the deep water flows and in the composition of water masses which are traced back to the different model formulations.

OXYGEN ISOTOPES, OVERFLOWS AND SLOPE CURRENTS

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Water masses and the processes involved in water mass formation can be identified by the ratio of the stable isotopes of oxygen ($^{18}O/^{16}O$). Such processes include evaporation/precipitation, sea-ice processes, glacial ice melt input and deep convection.

Water samples for $\delta^{18}O$ analysis were collected during September-October 1996 on the VIVALDI cruise section from Barra Head to Iceland. Of particular interest are the overflow waters from the Iceland-Scotland ridge system, the European Continental Slope Current and other waters within the Deep Northern Boundary Current.

Water masses and overflows will be discussed using CTD data, lowered ADCP and the $\delta^{18}O$ tracer.

BENTHIC STORMS IN THE GREENLAND SEA

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Over the past years, current meter moorings have been maintained in the Greenland Sea at 75N and circa 7W, some 180 km off the coast of Greenland. These moorings, the most westerly of mooring arrays spanning the continental slope, were designed to mark the outer edge of the East Greenland Current. Thus they were expected to register a small mean flow, as was indeed the case.

What was not expected however, was the large variation about this mean at the deepest of the current meters, placed about 50m above the sea floor at a depth of about 3300m. For example, one meter records an annual mean speed of 8 cm/s as opposed to an annual mean velocity of 0.2 cm/s. Isolated events occur (about 4 a year) where the bottom current greatly exceeds that recorded at overlying meters (at c. 1500, 350 and 80m depths).

These events last about a week and can have currents peaking at 43 cm/s, averaging at roughly 20 cm/s, the signal often being modulated by a strong 12 hour oscillation, (which is both the tidal and inertial period at this latitude). A strong correlation is observed with the direction but not magnitude of overlying currents. The temperature recorded at the lowest meter is constant to 1/100 degree.

The driving forces of these bottom intensified events, in areas of relatively flat topography, are still not understood. We consider various mechanisms, including the effect of sediment-loaded plumes originating at steeper parts of the slope.

The events exhibit many of the properties of benthic storms. Although such events appear to be quite rare, they contradict the belief of the calm abyssal depths and may have far reaching consequences for our understanding of the deep-sea.

THE EAST GREENLAND CURRENT AT 75N - ANNUAL AND INTERANNUAL VARIATION FROM MOORED CURRENT METERS.

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The circulation of the Greenland Sea transfers waters between the North Atlantic and Arctic Oceans. High salinity, warm Atlantic water enters in the southeast. Some exits to the Arctic via the Barents Sea and the Fram Strait, and some recirculates in the gyre returning south, somewhat modified, in the East Greenland Current, (EGC), which also carries Polar and Arctic water southwards.

The EGC is the western-intensified boundary current of the Greenland Sea gyre, and follows the contours of the continental slope off Greenland to between 75 and 70N, where it splits into a eastward recirculating arm and a continued southwards flow, which finally exits into the North Atlantic via the Denmark Straits.

Between 1987 and 1995, current meter arrays have been deployed across the continental shelf break at 75N, to measure the transport of this current. The dominant variation found is the seasonal rather than the interannual signal. In 94-95, when the coverage was particularly, the total transport varied from 14-40 Sv (+- 8 Sv) with an annual mean of 25 Sv. These figures agree (to within estimated errors) with the transports obtained from a combination of data over 7 years.

Such a large seasonal signal is not observed in current meter records further south at the Denmark Strait. The flat bottom Sverdrup transport calculated from ECMWF wind data agrees well in the annual average with that obtained from the current meters. It can account for the magnitude of the seasonal variation, but not for the summer transport, (when the calculated Sverdrup transport is zero). This suggests that a relatively small throughflow with thermohaline forcing is superimposed on a large wind-driven gyre circulation.

OA2 Open session on coastal/shelf sea dynamics

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TREND OF TRACE METAL CONTAMINATION IN SEDIMENTS OF THE ELBE ESTUARY FROM 1962 TO 1992

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Investigations of trace metal concentrations were carried out in a sediment core (length 4 m) of the "Mühlenberger Loch", a bay just downstream the harbour of Hamburg and covering several square kilometres. With damming up a lateral branch of the Elbe, the Süderelbe, in 1962, strong sedimentation of suspended particulate matter started. With each tide, fine-grained suspended particulate matter of the Elbe is transported into the "Mühlenberger Loch". About 1000 t per day of this material has been deposited on an average. This totals about 10 million t for the 3 decades of sedimentation. The amount of trace metals contained in the sediment comes to the 5- to 20-fold of the annual trace metal load that had been introduced into the estuary via the weir at Geesthacht in 1994. Maximum concentrations for most of the trace metals under investigation were assigned to the 1970s.

The Mühlenberger Loch is situated in a section of the river Elbe that shows a steep gradient of trace metal concentrations in particulate matter in the longitudinal profile. In this section, low contaminated particulate matter of marine origin mixes with highly contaminated fluvial solids. The mixing ratios at a fixed site depend strongly on the river discharge, i.e. high discharges correspond to high trace metal concentrations in the suspended particulate matter and vice versa. The resulting saisonal variations of trace metal concentrations may reach 300 % and can be distinguished as "annual layers" in the sediment core.

PARTICULATE LIPID COMPOSITION IN THE ICE-COVERED WESTERN LAPTEV SEA

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To investigate the features of particulate lipid composition, its distribution, sources and transformation in the Arctic marine environment, particulate matter samples from the Laptev Sea have been analysed by TLC-FID chromatography (Iatroscan-method). The sampling was carried out in 1995 during the PFS Polarstern expedition ARK XI/1 by means of Niskin bottles. The results show a high predominance of hydrocarbons and polar lipids in the particulate matter of the western Laptev Sea. Particulate lipid composition indicates on a considerable degree of organic matter transformation.The conservative lipid composition can be related to the fluvial supply of high degradated terrigenous organic matter. The high degree of particulate lipid transformation in the entire water column, including upper water layers, may be a result of the process of particulate lipid transformation inside the sea ice cover, wich enhances lipid oxidative degradation.

THE SUMMER COASTAL UPWELLING OFF EASTERN COAST CASPIAN SEA

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Coastal upwelling off eastern coast Middle Caspy is a seasonal phenomenon. It's forced by the north-west winds in summer. >From June to August the synoptic scale upwelling occurs to 6-10 times in this region, as result the decreasing of water temperature dominates over the seasonal heating of a sea. The Caspian Deep Water (CDW) lifts to sea surface from 20-40 meters with temperature 10-12=9CC and salinity 12.7-12.9 psu in during upwelling. Mean seasonal upwelling vertical velocities have values 0.002-0.003 sm/s. Surface horizontal currents have velocities 10-15 sm s. Filaments are discovery in the upwelling zone. Its lengths vary from 30 to 60 km. Interannual seasonal upwelling variability found with 10-12, 4-5 and 2-3 year oscillation periods.

NUMERICAL MODELLING OF HYDRO-LITHODINAMICAL PROCESSES IN TIDAL SEA BASINS.

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The aim of this study is to develops the method of calculation of bottom sediments transportation in the shallow sea basin due to tidal movements. The research is based on the Reynolds equations averaged over depth and tidal period as well as the suspension trasport equations including a source function describing the processes of stirring-up or accumulation of the sedimentary matter, and also the bottom sediments continuity equation. The sequence of operations can be briefly formulated as follows. First the curvilinear calculation grid is to be contsructed for the basin. Then the simulation of tidal movements in the basin is realised with the usual boundary conditions (normal currents equal to zero for the coastline and actual sea-level oscillations or currents data for the open boundary). Next the sediments discharge cause by the tidal is calculated and thereafter the resulting bottom deformation is determined using the sediments continuity equation to be taken in account in subsequent hydrodynamical simulation. Implementation of this method was made by means of a numerical model developed for the Bak-Bo gulf (South Chinese Sea). Numerical solution of abovementioned equation was obtained with using the curvilinear co-ordinate system adapted to the basin considered.

INVESTIGATIONS OF PHYSICAL FIELDS IN THE GULF OF RIGA: MEASUREMENTS AND MODEL OF VERTICAL TEMPERATURE AND SALINITY STRUCTURE WITH ACCOUNT FOR ICE FORMATION

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A dense set of measurements of temperature, salinity, oxygen and marine meteorology in the Gulf of Riga for last 25 years is analyzed. Together with the continuos hydrometeorological observation series it allows to draw the clear overview of the hydrology of this well-defined water body.
The method of water exchange calculation for this water basin is developed modifying the Knudsen's method of salt budget. Calculations with time resolution of half-year have been performed. They show good correlation of water exchange with the repetitiviness of the north-east sector winds.
A model for the dynamics of vertical temperature and salinity structure is developed, based on the upper mixed layer theory. It includes carefully balanced model for exchange on atmosphere-ocean interface, advective penetration of Baltic water into deeper layers and ice formation model.
Resolution of available observation data for forcing parameters (8-times daily) has allowed real-time calculation series for years 1992 to 1995 with high temporal resolution. These calculations have shown good quantitative agreement with measurements concerning all features of the vertical structure of physical parameters.

THE RESPONSE OF CANADIAN ATLANTIC SHELF SEAS TO METEOROLOGICAL FORCING

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As a part of an ongoing effort to develop an operational model of the circulation over the shelves of Atlantic Canada, we use a linear barotropic model to hindcast flow from Labrador Shelf to the Gulf of Maine. The model is forced by wind, air pressure and open boundary conditions. Model hindcasts are assessed by comparison against the data collected in the region. Simple statistical models are used to establish limits on the accuracy of the linear model hindcasts.

Having validated the model we examine the connections between different regions. We explore how wind driven flow on the Labrador and the Newfoundland Shelf affects the downstream shelves. It appears that the coastal trapped wave scattering on rugged topography of the Labrador Shelf prevents the signal from reaching the Gulf of Saint Lawrence. However, the wind forcing over the Newfoundland Shelf is a major source of variability for both the Gulf of Saint Lawrence and the Scotian Shelf. The connection between regions is frequency dependent. The results are used to provide a guidance for the development of data assimilative regional models.

ON THE STRUCTURE AND DYNAMICS OF THE BENGUELA UPWELLING CELLS

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The system of five cold upwelling cells was derived from daily AVHRR NOAA satellite thermal imagery of the Benguela upwelling region (15-32S) for the period January-February 1986 and April-June 1988. The locations of the cells correspond to the Cunene, Namibia, Walvis Bay, Luderitz and Namaqua cells identified by Lutjeharms and Meewis (1987). Their main characteristics (length, width, minimal temperature, temperature contrast with surrounding upwelled and open ocean waters) were investigated as like as the dynamics of each upwelling cell. It was found that the Luderitz cell, located at 25-27S, is the most intense and persistent feature of the Benguela upwelling region. The temperature contrast with the open ocean here reaches 6-8C. The locations of the cell centers were analysed together with bottom topography. The relationship between upwelling cells and filaments detected during the same time period is discussed.

OBSERVATIONS OF TIDALLY GENERATED INTERNAL BORES IN THE STRAIT OF MESSINA

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During the Atlantic-Ionian-Stream '95 cruise in October 1995, the space-time evolution of tidally induced internal bores was observed in the Strait of Messina. The measurements were carried out by means of a CTD (conductivity, temperature, depth) chain and an ADCP (acoustic Doppler current profiler) providing high resolution density and velocity fields. During the experiment, a strong seasonal thermocline was observed in the Strait of Messina, characterized by a discontinuity near the Strait's sill: the Tyrrhenian surface water north of the sill was heavier than the Ionian surface water south of the sill. As a consequence, while the northward propagating internal bore, consisting of Ionian surface water, developed as a surface jet, the southward propagating internal bore, consisting of heavier Tyrrhenian surface water, developed as a subsurface jet, intruding at a depth of about 100 m. These data indicate that horizontal density gradients play a crucial role in the evolution of tidally generated internal bores.

OBSERVATIONS OF BAROTROPIC AND BAROCLINIC TIDAL CURRENTS IN THE KATTEGAT.

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A small-scale field experiment in the Kattegatt was carried out with 4 bottom mounted profiling Doppler current meters within a 2.5 x 2.5 km area for a period of 3.5 days. Profiles were recorded at 5 minutes intervals, with a vertical resolution of 4 m. A large number of CTD stations were taken at the current meter locations.
Data analyses show that the tidal currents (semi diurnal) are strongly baroclinic following the pronounced two-layer stratification in the area. It is shown that the baroclinic tide is induced by the local topographic features of the area. The implication for the vertical mixing in the region is discussed.

TRANSITION FROM SINGLE TO MULTIPLE VORTICES OVER A SLOPING BOTTOM IN A TWO-LAYER ROTATING ENVIRONMENT

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Mediterranean water in isolated vortices called "Meddies" has been observed in oceanographic surveys in the Canary Basin. In this study a model of the formation and the development of Meddies has been investigated both theoretically and in laboratory experiments. The experimental apparatus consisted of a rotating tank with a sloping bottom in which a two-layer stratification was set up. Anticyclonic and cyclonic vortices were produced in the experiments by a source and a sink of buoyant fluid, respectively. Vortices were observed to develop at the interface of the two layers and their behaviour has been studied for a range of source/sink flowrates. At low flowrates a single vortex developed which extended to the west. At higher flowrates several vortices formed and moved to the west. The discussion will focus on the transition from single to multiple vortices. The stability/instability of vortices is studied in terms of the Rayleigh inflexion-point theorem. The theorem suggests the multiple state is reached when the westward velocity of the vortex is greater than a critical velocity related to the long Rossby wave speed. A comparison between westward velocities and long Rossby wave speeds for the experiments conducted will be presented. A theoretical model for a two-layered environment quasi-geostrophic flow will be compared to the experimental results.

EFFECTS OF MIXING AND OF BOTTOM TOPOGRAPHY ON THE STABILITY OF THE MEDITERRANEAN OUTFLOW ON THE IBERIAN SHELF

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The SEMANE'95 experiment at sea was conducted to evaluate the evolution of the Mediterranean outflow on the Iberian shelf, from the Straits of Gibraltar to the Tagus Palteau. Its hydrological and currentmeter data was processed and studied to assess the influence of bottom topography on flow stability, and the relations between this latter and mixing. To this purpose, temperature and salinity cross-sections and maps are analysed and potential vorticity distributions are computed.It shown that:
a) bottom topography has an essential influence first in steering the Mediterranean water undercurrents as separate cores, then in shedding eddies and filaments. Eddies produced over canyons may strengthen those generated by overshooting of the currents at capes;
b) baroclinic instability seems to preceed the oscillation of the undercurrents over the canyons. A cause for the vertically phase-shifted meanders to appear on the vein should be searched in potential vorticity reversals (Charney-Stern theorem);
c) the mixing processes change from Kelvin-Helmholtz instability in the rear of the Gulf of Cadiz (close to the Straits where vertical velocity shears are dominant in the vicinity of the water mass interfaces), to lateral intrusions and double diffusive mixing below the undercurrents, in the vicinity of the canyons and of the capes.
A simple stratified quasi-geostrophic model is used to highlight these processes and to quantify their sensitivity to changes in the physical parameters (width and speed of the undercurrents, diffusivity, canyon geometry). It is shown that quasi-stationary meanders or eddies can be generated by submarine canyons on a thermocline-intensified coastal flow.

MODELLING THE LONG-TERM WATER TRANSPORT IN THE MURUROA AND FANGATAUFA LAGOONS

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Mururoa and Fangataufa atolls have been the test sites of French nuclear weapons for several decades. Therefore, it is conceivable that, sometime, radioactive tracers will be released into the waters of the corresponding lagoons. It is thus appropriate to carry out studies aimed at gaining insight into the lagoon circulation and the exchanges with the Pacific. A three-dimensional model, including a lagrangian tracer transport module, is set up and validated against existing data. The water renewal time scales are computed to be of the order of a few months. The role of oceanic tides, wind stress, hoa inflow and stratification is investigated. The differences between the hydrodynamics of the two lagoons are highlighted. For the purposes of dose estimation, the complex, three-dimensional studies suggest that it may be sufficient to use a simple, "rule-of-thumb" model, comprising a first-order ordinary differential equation, a tremendous simplification which may be supported by physical arguments.

EFFECTS OF BOTTOM STRESS ON THE ADRIATIC SEA VERTICAL STRUCTURE OF SHELF CURRENTS

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The Adriatic Sea shelf circulation (down to 60 meters) has been investigated by means of a two dimensional POM implementation in a relevant section of the shelf area of the Northern Adriatic.
Seasonal winds and the thermal structure of the water column are found to be strongly dependent on bottom stress, as explained for the deep ocean by Mellor and Wang (1996). The bottom stress creates a bottom pressure compensation which introduces upwelling and downwelling along the sides of the basin.
This mechanism is speculated to regulate the winter to summer transition process and it is of relevance in determining the near shore shelf circulation.

ROTATING-TABLE EXPERIMENTS ON SUBINERTIAL WAVES TRAPPED TO A CONTINENTAL SLOPE AND SHELF IN A CONTINUOUSLY STRATIFIED OCEAN

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Energetic motions with timescales of several days are observed on most continental margins and accepted to be coastal-trapped waves: subinertial oscillations that can be trapped to the bottom by stratification but propagate along the coast in a waveguide formed by the sloping seafloor. We present results of laboratory wave simulations designed to keep as many dimensionless numbers (Rossby, Burger, Ekman, Reynolds, aspect ratio, normalized frequency) as possible similar to oceanic flow. The 13-m diameter tank rotates with Coriolis parameter f= 0.1 rad/s and is uniformly salt-stratified with buoyancy frequency N= 0.5 rad/s. A 50-cm wide continental slope of cosine-squared profile joins a shelf region 10 cm deep at the outer tank circumference to a central region H= 40 cm deep. A correlation particle-image-velocimetry technique, using neutrally buoyant particles lit by a 1-cm thick horizontal lazer sheet, measures velocities in a 2 m x 1.5 m area at several depths. Subinertial waves of along-slope wavelengths 2-3 m are easily excited and propagate with phase speed, group speed, and bottom-trapped three-dimensional velocity structure consistent with linear wave properties calculated numerically using experimental shelf-slope geometry and H, f, and N values. Preliminary runs examining waves incident on a cross-shelf canyon of width 75 cm will be discussed.

COASTAL DYNAMICS IN A SHELF-RESOLVING GULF OF MEXICO MODEL

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A shelf-resolving simulation of the Gulf of Mexico (GOM) circulation is done using the DieCAST Ocean Model. The GOM is an ideal test for coastal models, because of its well observed dynamics, tractable size domain and accurately known boundary conditions. Resolution is 1/12° and 20 layers.

Animated results show cyclonic wake eddies from Cozumel Island that significantly affect the Loop Current (LC) and Florida shelf water. They often lead to significant warm core eddy separation from the LC before major warm core LC eddy shedding. Fresh Mississippi water loops counter- clockwise as a shallow coastal plume all the way to the Campeche Bay in the south west GOM. Cross-shelfbreak freshwater spurts and two-way latitudinal shelf flow result from LC eddy encroachments onto the western GOM shelf. The broad LATEX continental shelf in the north west GOM has an elongated sinking region that was inferred from ship drift even before 1900.

Results are compared to many observations. These can be seen on the World Wide Web (http://www.cast.msstate.edu).

THE INFLUENCE OF RIVER RUN-OFF ON THE FLAW LEAD POSITION IN ARCTIC SHELF SEAS

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The influence of river run-off influence on the Siberian flaw lead position was studied during field investigations in 1994, 1995 and 1996 the basis in the Laptev Sea during all seasons of the year. These interdisciplinary explorations were carried out in the scope of the research project Russian-German: Laptev Sea System. Remote-sensing data have shown, that formation and distribution of the fast ice occurs in accordance with the intermediate water layer heat storage. As a consequence of convergence of surface water masses under the propagating river water a heat concentration up to 300000 KJ/m2 was estimeated in the river water outflow zones in water depths exceeding the depth of its direct penetration. As a result of strong density stratification in zones of river water run-off an intermediate water layer between 10 and up to 25 m water depth with an anomalous high heat storage preserves under the ice up to 25 cm in thickness in autumn. Calculations of the heat exchange have shown, that heat advection in conditions of intrusion stratification of the secondary thermoclinic hydrofront in combination with the double-diffusion processes on the peripheries of the outflow zone are responsible for the heat transfers to the bottom surface of ice. Based on our model the amount of heat which was transferred to the surface by this processes is great enough to reduce more than twice of the initial ice thickness on the periphery of the river water lens. It will cause fast ice edge formation in accordance with river water outflow zone. Thus, river run-off is controlling the formation of the fast ice edge.

NUMERICAL MODELLING OF THE CANARY UPWELLING

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This study is devoted to the investigation of the hydrophysical structure, circulation and dynamics of the Canary coastal upwelling zone (21°-24°N) with the help of mathematical/numerical modelling tools based on the 3D GHER Model. In the preliminary runs, the model has been applied in the case of a typical summer circulation. Non-homogeneous temperature and salinity fields are used to compute an initial geostrophic velocity field, from which the simulation has been started. The model is then operated under the following conditions: a horizontal mesh of 10x10 km within a 150-250 km domain; 30 non-uniform meshes on the vertical with higher resolution near the surface; real bathymetry and coastline; a total duration of the numerical experiment up to 35 days corresponding to the month of June; a typical wind blowing southwards with a speed of 12 m/s. From the preliminary runs of the model the surface coastal current flows equatorwards (25-80 cm/s) and upwelling takes place along. The rising of the isotherms and isohalines over the continental slope indicates that noticeable vertical motions up the slope occur only within a strip of about 20 km from the shelf break. The upwelled water is originated from depths which don't exceed 200-300 m and the cross-shelf circulation associated with coastal upwelling does not extend beyond the continental slope. A pole-ward flowing undercurrent is present over the slope. The model demonstrates two upwelling fronts over the shelf and the slope in the northern area (shelf width of 100 km) and a single front in the southern area where the shelf width is of 50 km.

NUMERICAL SIMULATION OF THE PARTICLE DISTRIBUTION AT A CONTINENTAL SLOPE

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The small scale distribution of concentration and size classes of different particles in the benthic boundary layer is of importance for the description of sediment transport processes at the seafloor. Particles of different quality in terms of density, composition and origin behave differently in the hydrodynamic regime close to the seafloor, leading to characteristic particle distribution profiles, due to hydrodynamic sorting. The amount and composition of particles determines the availability for deposition, but also the modification of particles in suspension. Among others, aggregation and disaggregation has been identified as one of the particle modifying processes.

A two dimensional numerical diffusion-advection model is used to simulate the temporal development of the small scale distribution of various particle fractions at an idealised continental slope. Based upon the resulting concentration profiles the various particle fractions are allowed to interact via aggregation. Here we present results of simulated distributions of various particles as well as the corresponding modification of particles due to the aggregation potential.

SYSTEM OF MESOSCALE EDDIES OVER THE CONTINENTAL SLOPE IN THE NORTH-WESTERN BLACK SEA

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Satellite imagery (summer 1993) and CTD-measurements (16-17 June, 1993) revealed compact system of two anticyclonic (AC) eddies and a cyclone(C) over the continental slope south-west of Sevastopol within the layer 0-300 m, diameters of the eddies being 90, 55 and 30 km and life times of more than 4 months, 1.5 month and a week, respectively. The opposing jets between the AC and C eddies were observed with cores in the upper layer and at a depth of 150 m (velocities of about 30 and 10 cm/s, respectively). The jets as well as associated cyclones at the long-lived AC eddy periphery and flows entrained by the eddy alternately from different directions conditioned the shelf-deep basin water exchange in the area.

COUPLED WAVE-HYDRODYNAMICS MODEL APPLIED TO THE BRISTOL CHANNEL

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The model couples dynamically the wave model WAM with a 3D hydrodynamic model, and its implementation to the Bristol Channel produced detailed information in space and time of the interaction between wind waves and tidal and wind-driven flow. The tidal range in the Bristol Channel exceeds 12 m, and strong westerly winds induce waves and storm surges that produce floods and navigation hazards. The coupling implies the computation of wave-dependent sea surface stresses to drive the hydrodynamic model, and a wave-dependent bottom friction coefficient to include wave effects which are important in shallow water. The hydrodynamic model transfers information on surface currents and water depths to WAM, which are used in the computation of wave refraction due to the presence of currents and bottom topography. A limited comparison with measurements is also included.

THE EFFECT OF TURBULENCE ON THE RATE OF FRAZIL ICE FORMATION DURING THE SPRING FLOOD AND ITS ROLE IN UPWARD SEDIMENT TRANSPORT IN THE SIBERIAN ARCTIC

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Layers of supercooled water from 5 cm to 1,5 m in thickness were recorded during the TRANSDRIFT IV expedition in May to June of 1996 for the first time. The maximal supercooling reached -0,8 deg.C in the vicinity of major branches of the Lena River Delta during the period of intensive flooding. More over frazil-ice formation was observed at the pycnocline. Strong supercooling is caused by intense intrusion of turbulent river water below the fast ice during the river flood. It leads to effective turbulent entrainment at the bound between the river and marine water masses. Based on oceanographic field data, which were obtained from fast ice during the flood development, the local Richardson number was calculated for the supercooled layer in order to estimate the rate of frazil-ice formation using the formulae, obtained in laboratory experiments. Our results have shown that the rate of frazil ice formation can be as much as 170 cm per day during the spring flood. In addition, frazil-ice formation during river break-up plays an important role for sediment incorporation in fast ice. However, field investigations east of the Lena Delta have shown that more than 7 g/m2 of sediments can be incorporated per day in fast ice.

TOPOGRAPHIC EFFECTS ON SHELF EDGE FLOWS

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Laboratory experiments are described in which the flow of an intermediate water current along a continental shelf is modelled. The distortion of the flow by seamount topography located close to the shelf edge is studied for cases in which the ambient conditions are respectively two-layer and continuously stratified. Measurements of density, velocity and vorticity fields have shown no significant dependence of the flow interaction upon the shelf geometry; the seamount is shown to have no significant effect upon the stability of the current. The interaction is shown to deform locally the density and velocity fields associated with the flow, provided that the summit of the seamount penetrates the level of the intermediate water flow. This results in splitting of the incident flow, the generation of attached eddy pairs in the lee of the seamount and the localised elevation/depression of the density surfaces in the interaction zone. The dependence of these deformations upon the controlling external parameters will be described.

THE INFLUENCE OF FRESHWATER RUNOFF AND ICE FORMATION ON CIRCULATION AND STRATIFICATION IN THE KARA SEA

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In the frame of a project on transport of radioactivity in the Arctic, the Hamburg Shelf Ocean Model (HamSOM) is applied to the Kara Sea. The baroclinic, 3-d circulation model is coupled to a thermodynamic and dynamic sea ice model and forced with monthly mean climatological ECMWF winds, atmospheric heat fluxes and river runoff.
The obtained model results reveal a strong seasonal variance. Simulated circulation fields appear to be in disagreement with the more conventional or 'classical' views of the Kara Sea circulation: A cyclonic current pattern in the southern Kara Sea, often described in the existing literature, was not observed in the model. The summer freshwater signal from the Ob and Yenisey rivers propagates north-westward into the central Kara Sea, instead of going eastward as often argued.
The vertical stratification is dominated by the freshwater signal and remains stable in most parts of the Kara See, even in winter. There is no indication of intense bottom water formation. Only in the south-western Kara Sea brine release through ice formation (haline convection) leads to deep mixing down to the bottom. This occurs mainly along the fast ice margins.

MODELLING THE TRANSPORT OF SUSPENDED SEDIMENT IN COASTAL WATERS AND ITS EFFECT ON SOUND PROPAGATION

R. N. Hewitt, S. D. Richards and A. D. Heathershaw (Defence Research Agency, DRA Winfrith, Winfrith Technology Centre, Dorset DT2 8XJ, United Kingdom) The propagation of sound in turbid coastal environments is affected by the presence of suspended particulate matter which attenuates sound energy through the processes of thermo-viscous absorption and scattering. The particle size range of particular interest is from about 1-10 μm. Modelling the advection and dispersion of this material is important in understanding its impact on the performance of acoustic measuring systems working in the range 50-300 kHz. In this paper we describe a simple 3-dimensional model which can be used to study the effect of sediment plumes on acoustic sensor performance. We solve the advection-diffusion equation for sediment transport using an Eulerian model based upon an explicit finite-difference method. This model is used to predict the effect of various quantities including the intensity of the advective and dispersive processes, the spatial and time configuration of the source and the sediment characteristics upon sound propagation. Results will be presented to demonstrate this influence for a variety of parameters which determine the plume characterstics.

GRAVITY CURRENTS IN ROTATING CHANNELS

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The release of pulses of buoyant water from rivers at times of high discharge, and from straits during neap tides, are ubiquitous features of the oceanography of coastal regions. Such events often result in the formation of gravity currents which may propagate for large distances along coastlines and produce high levels of turbulence and mixing. The degree of importance of Coriolis forces in these flows is determined by the ratio $W = L/R$, where L is the width of the 'channel' in which the flow occurs and R is the local deformation radius. Previous work has only considered the strongly rotating case of large W, or the nonrotating case of $W = 0$. Here we report laboratory experiments and theoretical work that considers the range of W which links these limiting cases. In the experiments, high-resolution image processing measurements were made which reveal, for the first time, the synoptic structure of rotating gravity currents. This structure was quantified and measurements of propagation speed were made. As W is increased, the structure of the flow undergoes a smooth transition and the propagation speed increases. A steady-state model was developed which isolates the dynamical effects associated with changes in W, and gives good quantitative agreement with the experimental results.

THE RHINE OUTFLOW STUDIED BY THE ANALYSIS OF ERS1/2 SAR DATA AND NUMERICAL SIMULATIONS

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Synthetic aperture radar (SAR) images acquired by the First and Second European Remote Sensing Satellite (ERS1/2) over coastal waters near estuaries often show sea surface signatures of river outflow fronts. In particular, the analysis of several SAR images showing the Rhine outflow region indicates that the outflow front is visible as a line of high radar backscatter. Location and form of the outflow front depend strongly on tidal phase and Rhine discharge. In order to simulate the dynamics of the Rhine plume in the outflow region, a two-layer, nonlinear numerical model based on the hydrostatic shallow water equation has been developed. Due to a numerical technique for moveable lateral boundaries, the model allows for the simulation of localized layers with an outcropping interface (front). The model is forced by imposing tidal and residual transport and river discharge at the open boundaries. The evolution of the Rhine plume as calculated by the numerical model is discussed with respect to tidal phase and Rhine discharge. Using a simple radar backscatter model relating the surface velocity convergence and shear to the relative radar backscatter, it is shown that the observed signatures of the Rhine outflow front can be explained by the variation of the surface velocity convergence and shear as calculated by the numerical model.

SPM AND TEMPERATURE MODELLING IN THE SOUTHERN NORTH SEA

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The relation between the summer stratification and the distribution of Suspended Particulate Matter is investigated using a 3D numerical simulation of the southern north sea. Horizontal gradients are maintaine using the Piecewise Parabolic advection scheme, and the vertical structu is determined by solving the turbulent energy equation with an algebraic mixing length. The effects of wave-current interaction are also consider The model, in its coarse grid form, successfully predicts the position o the tidal mixing front between East Anglia and the Dutch Coast; dividing shallow well mixed waters to the south from stratified waters to the nor The evolution of a single SPM population is followed (as a Eulerian tracer) from the winter periods of high input to the redistribution by t stratification in the summer. It is found for particles of silt size tha distribution mirrors that of the thermal front throughout the summer months: only south of the front and on the Dogger Bank does a significant proportion of the SPM remain in the water column. The reduced mixing in the stratified waters allows deposition in the north. During the Autumn, the break down of the stratification is successfully simulated resulting in a further redistribution of the SPM population. T model results are compared with observations from the North Sea Project in 1988/89.

MODELLING SEASONAL GYRES AND THE EFFECT OF WIND AND TIDE ON QUASI-STATIONARY DENSITY STRUCTURES.

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Recent observations confirm the existence of a stable cyclonic gyre in the western Irish Sea in spring and summer. The extent and persistence of the mesoscale (~50km) density driven flow is revealed by the largest ever deployment in European coastal waters of Argos tracked buoys. The density structure responsible - a dome of cold, dense water isolated beneath a strong thermocline - results from a local balance between solar heating and tidal stirring. The detailed dynamics of the gyre, and the interaction of the density field with wind and tide have been investigated using a three dimensional, primitive equation, turbulence closure numerical model. The results show the density field to be topographically locked during the heating season and immune to all but the strongest wind events. Diffusive weakening of horizontal density gradients is opposed by renewed solar input and continuous tidal stirring. The role of a weak,but distinct, transverse velocity field in advectively maintaining the density gradients is presented. The sensitivity of model results to different parameterisations of mixing is discussed. The gyre has implications for the retention of larvae and pollutants. A particle-tracking model is applied and the results compared with drifter trajectories and springtime larval distributions.

RAPID CHANGE OF SEDIMENT AND NUTRIENT DISCHARGES FROM THE YELLOW AND YANGTZE RIVERS BY HUMAN ACTIVITIES

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The Yellow and Yangtze Rivers are two of the biggest rivers surrounding the Pacific Ocean, which empty a huge amount of sediment and nutrient into the ocean, occupying more than 10% of the world total of riverine sediment discharge in the past. However, with human activities along the river besins rapid change has taken place. For example, owing to the dam construction, such as Sanmenxia completed in late 1960's and Xiaolangdi at present etc. the sediment discharge of the Yellow River dropped from a mean (1950-1969) of 1.2 billion ton/yr to a mean (1970-1992) of 0.7 billion ton/yr (by about 40% decrease) and the Yellow River dried up for more than 4 months for each of the last two years (1995 and 1996). Due to the dramatic increase of fertilizer applications in China, which went up almost 100 times in the last 40 years, nitrogen concentration the Yangtze River mouth was increased by 4-5 times from early 1960's to early 1980's and the dissolved nitrogen flux of the River was increased by 5 times from late 1950's to early 1980's. In the future, dam construction will be heavily continued for economy development in China, which will firmly cause decrease of riverine sediment discharge. On the other hand, soil erosion will cause increase of the sediment. However, we can not predict at present how serious the soil erosion, determined by land use, will be. In the present paper, the history of anthropogenic impact on coastal marine sedliment is reviewed with the Yellow River as example with special referene to the recent change since 1950 and the future tendency is argued.

TOPOGRAPHICAL EFFECTS IN COASTAL CIRCULATION

Yusuf Sinan Husrevoglu* and Emin Ozsoy*

The basic dynamics of coastal circulation as influenced by topography, coastal geometry, wind-stress distributions are investigated, through numerical solutions corresponding to idealized and application oriented problems. and by utilizing satellite and in-situ measurtements for special cases observed along the Turkish coastal seas. Simple effects of geometrical and topographical structures and wind-stress distributions are studied under steady and unsteady barotropic and baroclinic coastal flows. The basic dynamical problems are by nature non-linear and defined by competitive first order physical factors in a wide range of possible parameter space settings. Hence the approach adopted here is to obtain numerical solutions to possible flow configurations motivated by observed cases along the Turkish coastal seas, under the appropriate parameter ranges, as well as covering the parameter space of interest. The cases treated here are barotropic and two-layer stratified models with full nonlinearity and topographic steering terms as well as lateral, bottom and interfacial friction effects. Solutions are seeked for different forms of cross-shelf topography, coastal indentations (bays and headlands), canyons and ridges, shelf termination topographies, isolated topographic disturbances, and strait inflow configurations. The results are encouraging to explain observed features of such flows.

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SYNOPTIC VARIABILITY OF THE WHITE SEA SURFACE TEMPERATURE REVEALED FROM REMOTE SENSING DATA ANALYSIS BY GIS TECHNOLOGY

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Data sets from the different remote sensors cover different areas with different spatial resolution. To combine those with in-situ observations and simulations in studies of marine dynamics the geographical information systems (GIS) could be a great help.

For example the GIS technologies have been implemented to the NOAA AVHRR images in studies of SST synoptic variability in the tidal White Sea. A combination of raster- and vector-based GIS tools provided an accurate georeferencing of IR images with different acquisition time and transformed them to the uniform geographical projection and spatial resolution. The IR AVHRR data were further interpreted with the selection of Image Processing tools. Finally, the series of georeferenced interpreted IR images of the sea surface were put into the slide-show animation to visualize the SST dynamics.

This study has revealed the regions with intensive dynamic activity. The main patterns of sea water circulation responsible for SST variations in the open sea and coastal zone were recognized. The 2D-spectral analysis enabled to find out some peculiarities in the spatial and temporal characteristics of SST variability. Two typical states with high and low variability were found and related to the tidal rhythmic of the sea.

SIMULATION OF TIDAL CURRENTS OVER A CONTINENTAL SLOPE INFLUENCED BY STRATIFICATION AND VERTICAL VELOCITY

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A two-dimensional radial finite-differenced model is derived to simulate the vertical evolution of the semi-diurnal tidal currents over a continental slope with a limited continental shelf. The model is non-linear and includes a vertical velocity proportional to the horizontal cross-slope velocity, as observed in measurements. A quadratic vertical eddy viscosity is used, the parameterization of which has been chosen by comparison with results from a turbulent kinetic energy closure model. Tidal forcing occurs in deep water due to the astronomical potential imposed in Laplace's equations and generates barotropic surface slope and currents used as no-slip bottom conditions for baroclinic currents. Stratification appears in momentum equations by the mean of density baroclinic perturbation as well as the diffusion equation of temperature is added to the momentum equations, allowing to simulate different annual conditions of stratification influenced by the sea surface thermodynamical fluxes. Furthermore, wind is introduced as surface condition for the currents, as well as influencing eddy viscosity in the surface layer. The aim of building such a model containing influence of vertical velocity of great importance in slope regions, as well as stratification is to provide fields of tidal eulerian currents comparable to the observed real currents measured by Doppler currentmeters over the slope, and to get the basis for the study of lagrangian trajectories quantifying the mass transport from deep ocean to coastal shelves by interaction between tide and ocean-atmosphere processes.

STORM SURGE COMPUTATIONS FOR THE EASTERN IRISH SEA INCLUDING WAVE-CURRENT INTERACTION

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An overview of the mathematical development of a high resolution (1km) three-dimensional model of the wind driven flow in the eastern Irish Sea, including wave-current interaction is presented. The model is applied to the computation of the storm surge of November 1977, and the importance of local wind fields compared to farfield winds upon the surge in the eastern Irish Sea is examined. A significant improvement in surge elevations at Liverpool produced by using the high resolution grid is clearly demonstrated by comparing results with earlier coarse grid models. The further improvement obtained by inclusion of wave-current interaction effects is also demonstrated. Effects of high frequency perturbation of the wind field in space and time to simulate gustiness is briefly examined. Initial comparisons with current observations are considered.

POSSIBLE CHANGES OF THE MEAN SEA LEVEL AND MEAN CIRCULATION OF THE NORTH SEA DUE TO CLIMATE CHANGE

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General Circulation Models are designed to simulate the large-scale behavior of the atmosphere and the oceans. They yield credible results only on the scale of several grid boxes. The aim of this work is to "down-scale" the potential information of the climate model for the North Sea. For this, a regional version of the global ocean circulation model OPYC (regOPYC) is forced with the output data from the MPI climate model. The strategy is to believe in the large-scale information from the climate model. Therefore regOPYC consists not only of the North Sea but of the adjacent Baltic Sea and a big part of the North Atlantic. The input variables (besides variables used as climatological means) of the regOPYC model are the wind stresses, the kinetic energy (used for the mixed layer dynamic), the 2m temperature and the 2m dew point temperature (used for the calculation of the turbulent fluxes), solar radiation and precipitation. Sensitivity runs with regOPYC forced by the ECMWF reanalysis data show that the regional model is able to reproduce the long term fluctuations of the sea level to a high degree and fluctuations of the temperature and salinity to a lesser degree. Scenario calculations with the ECHAM3 "time-slice" data display possible changes of the mean sea level and mean circulation.

THE PO RIVER PLUME: A 3-D MODEL PROCESS ORIENTED STUDY

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Process studies with the Princeton Ocean Model(POM) show that the development and evolution of the Po River plume is primarily influenced by the amount of runoff and the magnitude and direction of the wind stress. In the absence of wind stress, the Po waters are advected mainly southward, but also northward, along the west coast and a pronounced coastal current is established. During downwelling-favorable winds (such as "bora") the southward coastal current is strengthened and the plume is confined along the west shelf. During upwelling-favorable winds (such as "scirocco") the southward coastal current is diminished and the Po plume fills the northern part of the North Adriatic shelf. Offshore removal of Po waters is possible during both "bora" and "scirocco" wind events and in particular after strong events and during relaxation periods of the wind field.
In the presence of ambient stratification, the density field is controlled by salinity near the Po delta. When the nearshore, low-salinity west shelf waters are colder than offshore waters (winter season) the density structure is determined by the competing effects of temperature and salinity. It is suggested that river input has a significant role in the dynamics and the general circulation of the Adriatic Sea, by influencing the overall cyclonic basin circulation and the west shelf coastal current.

THE DYNAMICS OF THE CASPIAN SEA COASTAL ZONE BY SPACE IMAGES

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Since 1978 the Caspian coastal zone has influence of sea level rise, followed a long period of its fall down. The coastal zone changes are seen at space images. Their study was carried out by compare the photopictures taken from Kosmos satellite (in scale 1:200 000) in periods of maximum regression (in the middle of 1970's), of early transgression (in the middle of 1980's) and in our days - in the middle of 1990's. As a result of multitemporal images interpretation, the schemes of transgressive changes in the coastal zone were compiled in scale 1:100 00-1:200 000 for 8 test areas at the sea edge of Volga delta, Kalmykian and Daghestan coastal zone. These schemes analysing has shown that influence of sea level rise is increases from the north to the south along with increase of offshore steepness and transition from predominantly accumulative type of the coast to prevailing erosion one . At the northern part of the area (with exception of the section near the Volga delta with it's "buffer" effect) flooding of mud flats with some wave reconstruction of coastal zone profile, formation of lagoones at backside of mud flats and some landward retreat of all coastal complex are the typical features of coastal zone dynamics. At the southern part of the Caspian coasts of Russia transgressive transformation displays within more narrow strip. Active wave reconstruction with cliff erosion at steep slopes and large beach ridge formation with wide lagoon behind it - at more gentle slopes - are the most important features here. Analyses of multitemporal space pictures show that aerospace monitoring is necessary for management of coastal zone under sea level rise conditions.

CURRENT OBSERVATIONS ON THE SITE OF NUCLEAR SUBMARINE "KOMSOMOLETS" WRECK

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The analysis of velocity observations data on the site of nuclear submarine "Komsomolets" (73.5 N, 13.5 E) is presented. These data were obtained during the expeditions of the research vessel "Akademik Mstislav Keldysh" in 1989, 91, 93, 94 and 95. The duration of the observations varies from 10 days to approximately 1 year. Data analysis has shown that the region is characterised by active and complicated dynamics. Direct current measurements have shown that one-layer circulation mode can be switched to the two-layer or even more complicated circulation patterns. Current observations have shown that the maximum observed velocities reach 56 cm/s in the upper layer, 43 cm/s in the intermediate layer, 42 cm/s in the lower layer and 22 cm/s in the viscous boundary layer. Relatively high instantaneous velocity values emerge as a result of superposition of a set of different spectral velocity components with temporal scales ranging from several hours to 1-2 months. As a result water parcels move along complicated tracks. However the net water transport averaged over approximately a year of measurements is estimated as 1 cm/s in the 300 meter layer over the bottom.

COUPLED ICE-OCEAN MODELLING OF THE BALTIC SEA

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Atmosphere, land, ice and ocean constitutes a strong coupled physical system. To understand the physics of this complex system, the utilization of coupled numerical models is necessary. One main aim of BALTEX is the development of coupled models to investigate the energy and water cycle in the Baltic region. A first step towards a fully coupled atmosphere-ice-ocean model with hydrology included is the development of a coupled ice-ocean model driven by the atmosphere and river runoff. A coupled ice-ocean model of the Baltic Sea is presented. The oceanic component is a three-dimensional baroclinic model of the whole Baltic Sea, with a horizontal resolution of 5 km and 28 vertical levels specified. The glacial component is a dynamic-thermodynamic ice model based on the Hamburg Sea Ice model, with the same horizontal resolution. The coupled system is driven by atmospheric data, mostly provided by the Europa-Model of the German weather service. River runoff is taken from a monthly mean data base. The effect of sea ice on the circulation and the water mass exchange with the North Sea is investigated for the BALTEX years 1992/1993.

OBSERVATION OF THE STRAIT FLOW RESPONSE TO THE FORCING VARIATIONS

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An intensified 10-day measurement of temperature, salinity, nutrient concentration, current velocity (using Aanderaa, ship-mounted and self-contained ADCP), meteorological parameters and sea level was carried out in the Irbe Strait area in June 1995. The study was focused on the frontal circulation and its evolution in time in a transition area between the Baltic sub-basins. The intermittence of westerly and easterly wind with period of 2 days resulted in the sea level fluctuations and the oscillating current superimposed on the typically estuarine strait flow - outflow of the Gulf of Riga water in the northern part of the strait and inflow of the Baltic Sea water along the southern slope of the strait. The cross-covariance functions calculated for the time sequences of along-channel wind stress, water level difference between outer and inner tide gauges and along-channel current velocity indicated to a relatively quick response of the current velocity to the changes of the sea level difference (with time lag 1.5 hours and 6.8 hours in the upper layer of the northern part and in the southern slope, respectively). The wind stress and the horizontal pressure gradient due to the sea level difference appeared to work against each other with time lag of about 6 hours. A discussion on the dynamics leading to the coexistence of forcing-dependent two-day current oscillations and a quite stable regular flow scheme in the Irbe Strait is presented.

ON THE NONLINEAR HELMHOLTZ RESPONSE OF ALMOST-ENCLOSED TIDAL BASINS WITH SLOPING BOTTOM

Leo R.M. Maas (Netherlands Institute for Sea Research, P.O.Box 59, 1790 AB Texel, The Netherlands)

Short, relatively deep tidal basins, which are connected to the open sea by a narrow strait, may exhibit either an amplified (resonant), or damped (choked) response to the tide at the entrance. Here particular attention is given to the lowest mode of response, which is the Helmholtz or pumping mode for which the sea level within the basin executes a spatially uniform oscillation. When the basin's side-walls slope, the restoring process of this oscillator becomes nonlinear. Possible consequences of this nonlinearity are that the basin may either exhibit long-lasting high-waters and short, peaked low-waters; a long-term, regular modulation of its tidal amplitude; a chaotic modulation of its tidal amplitude; or 'bended resonance horns', implying that resonant and choked tidal responses may exist simultaneously for the same parameter regime. Related field observations will be
discussed.(Paper submitted to J. Fluid Mech.).

TOPOGRAPHIC FILTERING AND REFLECTIONLESS TRANSMISSION OF LONG WAVES

Leo Maas (Netherlands Institute for Sea Research, P.O.Box 59, 1790 AB Texel, The Netherlands)

The equation governing the passage of linear monochromatic, long waves over variable topography can be transformed into a Schrödinger equation. There are several transformations accomplishing this. First, a 'naive' transformation (in which only the horizontal coordinate is stretched) yields a potential energy function ('potential') that is non-vanishing, even if the slope in topography vanishes. Second, a transformation in which also the surface elevation field is stretched leads to a 'potential' that does vanish outside the sloping region. The latter has the property that it displays scattering against a background of adiabatic variations. For smooth bottom profiles, typical for the continental slope, it is shown that
the potential has a positive lobe, the top of which acts as a 'topographic cut-off frequency'. This lobe is missed by piecewise-linear topographies. Despite the fact that the topography in general acts as a high-pass filter it is
shown that there exist some particular, smooth bottom-profiles for which long waves, obeying certain conditions, can pass reflectionless. (Ref: Maas, L.R.M, 1997, J. Phys. Ocean. 27, 195-202).

MODELING THE WATER EXCHANGE BETWEEN NORTH AND BALTIC SEA

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Within BALTEX (the Baltic Sea Experiment), a three dimensional regional model of the western Baltic Sea has been developed to calculate water and salt exchange between the North Sea and the Baltic Sea. To resolve topography in the Danish Straits, a resolution of one nautical mile in the horizontal and 3 m in the vertical direction is used. The model domain comprises Kattegat, the Belt Sea, Arkona and Bornholm Basin. Time and space dependent active open boundary conditions for temperature, salinity and surface elevation are implemented. Realistic initial and forcing fields from the DWD Europe Model are used. September 1992 until September 1993 was chosen as a test period, including the latest major inflow event. As the salt budget of the Baltic Sea and the heat fluxes between atmosphere and ocean are influenced by mixing processes, a turbulence model of the $k-\epsilon$ type is embedded. Two additional prognostic equations for turbulent kinetic energy and dissipation are solved numerically at every gridpoint of the three dimensional model. The results of the improved model are compared to hydrographic data from ship cruises and discussed with reference to the water exchange between the North Sea and the Baltic Sea.

DYNAMIC APPROACH TO THE SEA WATER VARIATION IN THE COASTAL ZONE OF CENTRAL CHILE (27-31°S)

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A series of hydrographic measurements have been obtained off the coast of Chile, between 27 and 31°S, with the purpose of characterizing the oceanographic conditions of the area. The measurementes analyzed have been collected from 1992 to 1996, mainly on august-september. The hydrography shows the presence of three upwelling focus, south of 30°S, at 29°S and 27°20'S. Remotely sensed sea surface temperature indicate different pattern of spatial extend of the upwelled waters. The upwelling center at 30°30'S seems to be produced by wind forcing as the measurements there coincided with the equatorward wind period event. On the other hand, the others seem to be reinforced by bathymetry as suggested by relative vorticity estimates. Seasonal variability of the water masses is observed in the upper layer (0-500m) causes by alongshore currents changes, crossshore intrusions of water masses, and long period internal waves. Estimates of geopotential anomalies relative to 500 db suggest a mean equatorward near-surface flow over the narrow continental shelf and slope throughout the study area and poleward flow at depth between 100-300 m, and 70 km offshore.

RESPONSE OF THE ADRIATIC SEA LEVEL TO THE AIR PRESSURE AND WIND FORCING AT SUBSYNOPTIC FREQUENCIES

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Six to eight years of sea level, air pressure and wind data, collected at three locations along the east Adriatic coast, are used to examine variability at low frequencies (≈0.01-0.1 cpd). Seasonal energy spectra show that for all the time series energy at time scales between 2 and 100 days is greater in winter than in summer. There is substantial wind energy in subsynoptic frequency range, the greater part of which is in the longshore component. In order to explain the inverse barometer (IB) overshoot, recorded throughout the Mediterranean, response of sea level to the air pressure and wind forcing at low frequencies was examined through multiple linear regression and cross-spectral analysis. The inclusion of wind stress from three coastal stations, or of the first principal component mode of wind stress, reduces but does not fully account for the IB overshoot. A simple model of a linear system with two inputs, one of which is measured with error, and one output, is developed. It is shown that the parameter estimates of such a model are biased by measurement error of the input.

APPLICATION OF EOF ANALYSIS TO THE ESTIMATION OF GEOSTROPHIC CIRCULATION FEATURES IN THE OCEAN

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The application of EOF analysis to the estimation of geostrophic circulation features is studied with particular reference to spatial series of near-synoptic profiles of CTD data. We show that profiles of specific volume anomaly can be approximated closely by a small number of their leading principal components (PCs). Consequently, horizontal interpolation of expansion coefficients associated with a few vertical (EOF) modes provides an efficient method of generating a truly 3D representation of the dynamic height field and geostrophic flow structure, which retains the full resolution of the input profile data. Although this approach requires profile data spanning the full depth range of interest, PCs of shallow profiles can be estimated using a simple least-squares regression method. This procedure allows realistic estimates of dynamic height in (shelf) regions shallower than the reference level used for geostrophic computations. There appears to be no unique solution to the problem of identifying an optimal subset of PCs for the purposes of spatial analysis. However, both spatial correlation and cross-validation analysis yield consistent results in identifying the vertical models accounting for most of the resolvable between-profile variance.

Using an Isopycnal Coordinate Ocean Model (MICOM) in gravity waves study

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The dynamical equations of the MICOM model are used to simulate internal tides generation in presence of a steep bathymetric gradient. We assume a vertical plane representation with a bathymetric variation due to the continental slope. Internal tides are generated by the passage of the surface tide over the bottom slope. Generation and propagation of these internal tides are forced by boundaries conditions on the barotropic mode : the time evolution of the sea surface and associated vertical mean currents is given by a linear solution corresponding to a Poincare wave at the tide frequency. Results on the baroclinic mode (internal tide) for different initial conditions of the vertical stratification, are in good agreement with other numerical models results (though these latter are based on the rigid lid approximation). Using non-linear barotropic equations allows to get an estimate of the rectification topographic effects due to the tide. The interactions between both baroclinic and barotropic modes generate spatial variations of the sea surface at the baroclinic wavelength. However, for the different numerical simulations, this surface signature of the internal tide is still weak : it represents about one per cent of the surface tide amplitude estimated in an homogeneous ocean.

GENERATION OF INTERNAL WAVES OVER A SHELF: AN EXPERIMENTAL STUDY

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We study the generation of internal waves by a barotropic current flowing over a shelf. In the 13 m rotating tank we put an annular shelf, 1.5 m wide and 0.3 m high. A Cos^2-shape slope, 50 cm wide, links the shelf and the deep region. The tank is filled with a two-layer fluid and a central cylindrical paddle generates a barotropic forcing. We record the interface variations with time at several locations along a radius of the tank both in the deep water, over the slope and over the shelf.
We first check that no orthoradial movements are generated. We focuss on the generation of the internal waves at the shelf break. It appears that rotation modifies the amplitude and the celerity of waves which are generated but not the generation process itself. Thus, with or without rotation, when the current is oriented to the deep water, a depression appears, the amplitude of which is maximum when the current is maximum. When the current weakens this depression starts to split in two parts, one evolving toward the deep water and one toward the shelf. The process repeats itself at each tidal cycle. This often leads to trains of nonlinear waves. However, for large tidal periods, only linear internal tides are generated. The amplitude of the internal waves increases with increasing internal Froude number at the shelf break. The amplitude of the waves decreases with increasing rotation, whereas the celerity of the waves increases with increasing amplitude.

DETAILED OBSERVATIONS OF INTERNAL WAVE CIRCULATION AND PROPAGATION AT THE MALIN SHELF EDGE DURING SESAME 1996.

by S Ramsey (Defence Research Agency, Winfrith, UK), **T Sawyer**, K Kelly, J Scott and J Small

Observations of internal waves were made at the Malin shelf edge using towed ADCP and thermistor chain, yo-yo CTD and WAVEX radar during SESAME (Shelf Edge Studies Acoustic Measurement Experiment), a part of SES, in August-September 1996. These measurements provide a unique high resolution dataset demonstrating internal wave generation, propagation and vertical circulation within the waves. Repeated tows across the shelf break during complete tidal cycles were made to investigate the formation and evolution of the internal tide and high frequency solitary waves.

Plots of water particle vertical circulation within an internal wave train show clear evidence of discrete vertical cells, with areas of convergence and divergence extending to the surface. This has implications for identifying internal waves from imaging radar such as SAR. Estimates were made of internal wave propagation speeds from simultaneous yo-yo CTD and radar data. The measurements of vertical circulation and propagation were then compared to results from 2 layer and modal internal wave theory.

AN OCEAN GENERAL CIRCULATION MODEL APPLIED TO A SMALL BASIN WITH COMPLICATED HYDROPHYSICS AND BATHYMETRY

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Synoptic time-scale field campaign data, IRBe strait Experiment-95 (Gulf of Riga in the Baltic Sea) and hydrographic fields simulated by 3D ocean general circulation model (OGCM) were compared to estimate the usability of the OGCM in the area with complicated topography and e volving salinity front. The coincidence, including the position and shape of the permanent salinity front, the horizontal shift of the front in the upper and lower layers, the propagation of the riverine water and the thermocline location, was rather good. Particular discrepancies result from the crude horizontal model resolution, excluded air-sea heat exchange, unsatisfactory turbulence closure scheme, underestimated river discharge rate as well as from rapid changes of hydrographic structures in response to the fluctuating wind, which could not be captured by the synoptic-scale survey. The salinity and temperature rms errors calculated between the pairs of measured and modelled values for each model layer range between 0.31-0.5 psu and 0.5-2.3 C, respectively.

A NUMERICAL STUDY ON VORTEX DYNAMICS

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A nonlinear numerical model based on the reduced gravity, hydrostatic shallow water equations has been developed in order to simulate the dynamics of surface vortices with outcropping interface. Due to a technique for movable lateral boundaries, the model allows for the simulation of expansions and contractions of the surface area. As a model validation, the results obtained by the numerical model are compared with the results of an analytical model. These analytical solutions refer to a special class of frictionless circular vortices with quadratic depth and linear velocity profiles. It is shown that the spatial and temporal evolution of the vortex shape and the associated velocity fields are adequately described by the numerical model. Moreover, different numerical simulations are carried out by assuming different parametrizations for interface friction and entrainment. The results indicate that interface friction is much more efficient than entrainment in producing the vortex decay.

Development of North Sea and Baltic Sea heat content during the 1980s.
Results of a coupled ice/ocean model.

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Results of a coupled ice/ocean model for the North Sea and the Baltic Sea are presented. The model was calculated in a fully prognostic mode from 1980 to 1990, by using the ECMWF-reanalysed data as meteorological boundary conditions. The variability of oceanic heat content, sea surface temperature and intermediate water temperature will be discussed and related to the variability of the atmospheric forcing. Differences between North Sea and Baltic Sea are evaluated.

Investigations of thermohaline stratification and instabilities in the German Bight

Corinna Schrum (Zentrum für Meeres- und Klimaforschung, Universität Hamburg, Troplowitzstr. 7, 22529 Hamburg, Germany).

An eddy resolving model for the German Bight is used to investigate processes involved in development of stratification in the German Bight. Horizontal distributions of the conversion terms between mean kinetic and potential energy and mean eddy kinetic energy are investigated and the contribution of mesoscale turbulence to the mean flow field is quantified for different wind conditions.

CALCULATION OF CIRCULATION IN THE GULF OF RIGA BY A SHALLOW WATER MODEL

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The Gulf of Riga is a well-defined semi enclosed water basin of average depth 25.5m connected with the Baltic Proper by two straits.
The formulation of the shallow water model for the Gulf of Riga has been given together with the physical situation analysis. Conditions of applicability of such a model without accounting for the density stratification have been investigated. Model can be applied for qualitative investigations of the reaction of the Gulf to meteorological forcing, obtaining the typical flow and surface elevation patterns. It is suitable also for real-time calculations in the autumn-winter periods. Calculations for characteristic flow patterns as well as for characteristic transient situations and real time periods have been performed. The results have been compared with the water level observations. The comparison has shown reasonable agreement between model predictions and observations for the autumn periods with negligible stratification. The real time calculations indicate absence of permanent wind-driven currents in the Gulf of Riga caused by rather strong variability of meteorological forcing. Calculations show that structure of interchanging cyclonic/anticyclonic vortexes weakens water exchange between northern and southern parts of the Gulf and, as a consequence, between the Gulf and the Baltic Proper.

VARIATIONAL ASSIMILATION OF THE HFR SURFACE VELOCITY DATA INTO A FINITE ELEMENT TIDAL MODEL OF THE STRAIT OF DOVER

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The augmented Lagrangian multiplier-penalty method is applied to invert tidal gauge and High Frequency Radar (HFR) surface velocity data within the framework of a 2D finite element tidal model. Identical twin data assimilation experiments have shown good performance of the method. The scheme is applied for reconstruction of the predominant constituents of the tidal spectrum in the Strait of Dover. Results show an extreme usefulness of the surface velocity data for correct determination of the tidal signal at the open boundaries of the basin.

DYNAMICS OF DENSE WATER CASCADING OVER A SHELF BREAK

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Mesoscale near bottom plumes of dense water are common features in the shelf/slope zone and have been reported for example in the Irish, Black and Adriatic Seas. These structures can generate density-driven flows which have important implications for the dispersal/retention of contaminants, suspended sediments, water formation as well as marine biota. The evolution of dense water plume has been studied analytically and numerically. Results provide information about along isobath translation, 3D plume evolution and cross-slope fluxes. It is found that the plume shape is destorted with time as the force balance depends strongly on the local plume thickness. This results in a wider dispersion of water particles over the adjacent area. In agreement with the reported observations, the theory predicts that at a developed stage the thickness of the water plume is of the order of double the Ekman scale. Entrainment of water from the upper layer increases the downslope propagation while an alongslope current, depending on its direction and velocity, may assist or prevent downslope cascading. The theory is specifically applied to recent observations of a cold, saline plume which had cascaded over the shelf break onto the continental slope northwest of Scotland. Numerical results show that the observed density structure would have formed in about two days.

Photosynthetic Activity And Regeneration Of Nutrients In The Bottom Layer Of The Northern Adriatic Sea

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The Northern Adriatic Sea is a land-locked and relatively shallow (max. depth~60m) sea; its waters are strongly influenced by fresh water inputs and air mass dynamics.
The distribution of nutrients a few meters above the bottom, during the six seasonal cruises of the EC Environment-ELNA project from June 1993 to November 1994, reveals the existence of three different areas in the Northern Adriatic Sea: a) nutrient poor areas with photosynthetic activity, b) nutrient poor areas and c) nutrient rich areas related to the Po river discharge.
The nutrient poor areas with photosynthetic activity are characterised by high oxygen saturation (> 100), positive values of preformed nitrates while the regenerated remain negative.
The nutrient regeneration, calculated by using the stoichiometric model proposed by Degobbis for the Northern Adriatic, appears markedly higher in the nutrient rich areas. The seasonal circulation regime of nutrients in the Northern Adriatic affects the spatial distribution of these different areas.

Observations of the Slope Current of the North-West coast of Britain.

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We present the first results from a to study of the continuity and behaviour of the Scottish slope current system, from the Malin to the Hibridean Shelf on the basis of a spatial survey which was carried out on board the RSS Challenger between the 17 August and the 1 September 1995. The survey consisted of a zig-zag across and along the shelf between 55° and 58° N, in which a detailed measurement of the water characteristics were measured by means of CTD and XBT casts as well as the continuous recording of velocities down to 320 m by means of the ship-borne ADCP, these observations were supplemented by moorings in an across-shelf line, the moorings were capable of measuring temperature and velocity at different levels of the water column.

Preliminary results show that the Scottish slope current has a mid-water core centred at about 200 m deep. Related to this high velocity core we can find a characteristic core of high salinity water S < 35.35 PSU, located between 200 and 500 m and a maximum in beam attenuation grater than 0.48 m^{-1} located in the shelf break region at about 400 m deep. In the same region we observe that the 9.5 °C isotherm show a pronounce downward tilt towards the continental slope. Since that density is dominated by temperature, this implies a north-eastward geostrophic flow. This north-eastward flow has been confirm by both moored current meter measurements and ship borne ADCP, showing a core of maximum along shelf velocity of the order of 16 cms^{-1} at about 200 m deep.

ON THE VARIABILITY OF BLACK SEA CIRCULATION WITH SYNOPTIC/INTERANNUAL TIME SCALES

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The paper addresses the specific appearances of eddy processes when the basin scales are comparable with the baroclinic radius of deformation. The Black Sea is used as a test basin. Eddy variability is analyzed using simulation data and compared with existing observations. Bryan-Semtner-Cox model with horizontal resolution $\Delta\varphi=1/10°$ and $\Delta\lambda=1/6°$ is forced with annual mean wind stress. The buoyancy flux at sea surface is proportional to the deviation of the current density from the annual mean climatological data. Sensitivity studies on different forcing and on the topographic control are carried out. Synoptic periods are estimated to be about 0.5 year. Eddies form in the eastern Black Sea and propagate to the west with a speed of about 3 cm/s. The Black Sea narrow section, between the Crimea Peninsula and the Turkish coast, strongly affects the eddy propagation. The dissipation increases in the western basin, where eddies slow down and their scales become small. Energy spectra give indications that inverse cascade might occur. The bottom topography control has an utmost importance for enhancing interannual baroclinic oscillations. Transitions between different states in the circulation are found in the model data. They are accompanied by transition in the vertical circulation and are due to instabilities, developing in the gyre after the slope of the pycnocline reaches some critical value. Model simulated phenomenology, time and length scales are compared against observations.

INFLUENCE OF COASTAL UPWELLING ON DYNAMICS OF OXYGEN AND HYDROGEN SULPHIDE IN THE BLACK SEA

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The hydrodynamic model was used to study the upwelling and its influence on the distributions of oxygen and hydrogen sulphide in the Crimean coastal zone of the Black Sea. The chemical reaction between these dissolved gases was also taken into account. The upward fluxes of cold bottom water are accompined by displacement and penetration of oxygen and hydrogen sulphide into to the layers enriched by these gases. As a result the extensive co-existance zone arises over the shelf break at place of upwelled water. The area with small oxygen concentration remains over the shelf break in the places of upwelled cold water after the end of chemical reaction between hydrogen sulphide and oxygen in the co-existance zone. This extended area with low oxygen concentration may be considered as a "trace" of upwelling event.

RESOLVING THE FINNISH COASTAL CURRENT

Tapani Stipa (Department of Geophysics, FI-00014 University of Helsinki)

Since the 1930s, a cyclonal circulation has been hypothesized for the Gulf of Finland. However, little has been known about the actual current structure associated with it.
Recent high resolution measurements presented here reveal that this circulation often takes the form of a narrow semipermanent buoyant jet flowing westward at the outskirts of Finnish coastal archipelago. Cross-gulf ADCP and CTD transects from the ice-free season are analyzed for the orthogonal characteristics of this circulation and the associated fluxes.

PERIODIC COMPONENTS IN THE CURRENTS OF THE BALTIC SEA

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In the paper a summery of the variability of currents of different time and space scale in the different basins of the Baltic Sea, where current measurements were carried out, is analysed. In the Gulf of Finland due meteorological forces the upwelling and downwelling intermediary within 20-30 days is observed. The eddy-field, passing the mooring stations, creates the 5-10 days variability in the current velocity components in the Baltic Proper. A case of baroclinic instability of topographic waves with periods of 7-8 days in the two-layer system was observed and interpreted. The topographic bottom-trapped, slope-trapped and shelf waves were observed in many regions. The diurnal tidal motion and seiches were observed in the Irbe Strait and in the Gulf of Riga. The inertial oscillations are the frequent part in the current variability - in many cases amplified by wind or suppressed by longer-period variability.

SIDE-SCAN SONAR FEATURES IN THE ROCKALL TROUGH, OFFSHORE IRELAND

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A high-resolution (GLORIA) side-scan sonar survey covered approximately 200 000 km^2 in the Rockall Trough, west of Ireland. A number of large slump structures are identified along the southeastern flank of the Trough. They show well-developed cuspate extensional slump heads. Translational mid-slump differential mass movement produced a series of NW-SE intra-slump translational shears. Compressive slump toe features occur towards the base of the slope. The slumps have a general NE-SW orientation, slightly oblique to the basin edge probably reflecting the seismic reactivation of inherited caledonoid structural features. Canyons at the northern end of the Porcupine Bank are interpreted as re-entrant features which chanelled sediment into deeper water. The major feature imaged along the western margin is the Feni Drift, a large elongate depositional complex. This contains sinuous dune-sized sedimentary features with variable crest orientations which may represent basinward-directed creep structures. Debris flows have also been identified along the western margin of the Trough.

THE INFLUENCE OF HYDROTHERMAL FLUXES ON BIOGEOCHEMICAL PROCESSES IN PALAEOHORI BAY, MILOS HYDROTHERMAL FIELD, ON THE HELLENIC VOLCANIC ARC

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Suspended particulate matter separated from hydrothermal waters collected by scuba diving from a considerable number of vents in Palaeohori Bay, Milos on the Hellenic Volcanic Arc were analysed for Fe, Mn, Cu, Pb, Al, Ba, Sr, Ca, Si and Li. Gas and water flow measurements were also carried out during the sampling procedures. The compositional variability of suspended particulate matter is investigated in relation to pH, conductivity, dissolved oxygen, Cl- and F- variations and the influence of hydrothermal fluxes on geochemical/ biogeochemical processes are deduced. It is revealed that particulate Si and Cd increase in the hydrothermal vents of low conductivity, while Ba increase with i ncreasing gas and water flow. Si and Cu increase in the waters of low F- concent rations while F

A HYBRID MODEL FOR NEAR-FIELD PARTICLE DISPERSAL WITHIN A SUBMERGED *AMPHIBOLIS ANTARCTICA* SEAGRASS MEADOW

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Seagrasses are able to attenuate water flow which is known to result in an overall dampening of the ambient flow. The hydrodynamic micro-climate consequently created within seagrass meadows and their immediate surroundings has implications for particle transport (including pollen) and settling within seagrass meadows. *In situ* 3-D velocity measurements within and above *Amphibolis antarctica* meadows in a coastal, swell wave dominated, regime revealed highly variable flow in both space and time. An overall dampening of the ambient flow was observed within the meadows. Below a flow minimum, 25 cm above the seabed, an increase of flow towards the seabed was observed. The modal structure of the flow within the meadows differs from the general view of vegetation as a -viscous- boundary layer and within-meadow particle transport. This was explained by a 3-D hydrodynamic (HamSOM) model coupled to a plant-canopy model.
A hybrid, deterministic and statistical, model on pollen (particle) dispersal was developed utilising observed flow dynamics. Results of the hybrid model show that the combination of plant structure and flow dynamics lead to particle capture in areas where the hy drodynamics were considered less than favourable for capture, thus highlighting the importance of plant-flow interactions. This suggests that, as a response to the hydrodynamic environment, the same species of seagrass may have differing plant structures to compensate for their habitat.

MULTIPLE STATES IN DOUBLY DRIVEN CONVECTION IN ESTUARIES, SHELVES, AND MARGINAL SEAS

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If two components effect density, a convecting fluid may possess more than one stable state for the same boundary conditions. Although principally applied to climate models, an exciting new wide range of applications to estuary and coastal water circulation is indicated. Laboratory experiments give new insight into their physical nature. A box of water heated from below was exposed to constant flux of salt water from above. The box was connected to a large body of fresh room temperature water through tubes. If buoyancy flux of salty water approximately equaled the decrease in density from heating, two states were found. One had very slow exchange of hot and very salty water with density due to salinity greater than that from temperature. The other state had faster flow in the opposite direction of warm and low salinity water. Parameters are explained and values given for estuaries, shallow seas and marginal seas. For example, during the onset of winter, bays with density dominated by salinity may suddenly change to cold-water (temperature) driven bodies. Two examples of coastal models driven by stress and heat flux also exhibit multiple states. Thus some coastal regions have conditions that make the T,S, and velocity state difficult to predict, and any one state my exhibit sudden dramatic changes.

A THREE-DIMENSIONAL MODEL OF THE BALEARIC SEA: RESULTS OF SOME IDEALIZED FORCING STUDIES

J. Xing and A. M. Davies (POL, Bidston, Birkenhead, L43 7RA UK)

A three-dimensional baroclinic model of the Balearic sea is developed to study the regional circulation of the Balearic basin in the west Mediterranean sea as part of an EC funded project to study the Fluxes Across Narrow Shelves (FANS) in the region. Using some idealized boundary input, river discharge and wind stresses the model integration is carried out in order to understand some basic processes controlling the circulation, in particular, the flow off the northeast coast of Spain. Calculations show influences of strong topography features (such as a very narrow shelf changing to a wide shelf) on the flow. The coastal current due to the Ebro river discharge seems to have little interaction with the shelf edge flow. However the river plume is very sensitive to the wind stress. A process study is also carried out to investigate the interaction of fresh water plume, narrow shelf and shelf edge, and a canyon cutting across the shelf. It shows that the shelf edge and canyon topography have a strong influence on the depth-mean flow in the case of a zero ambient stratification. However, this influence is greatly reduced in the case of a non-zero ambient stratification.

ON THE MECHANISM OF DENSITY COMPENSATION IN THE WESTERN ADRIATIC SEA COASTAL CURRENT (WACC)

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Density compensated temperature and salinity gradients are often observed in mixed layer fronts. The mechanism of density compensation has been studied trough the use of the Princeton Ocean Model (POM) implemented in the Adriatic Sea, where one of the most prominent features of the general circulation, the Western Adriatic Coastal Current (WACC), is characterized, during the winter sea son, by antagonistic horizontal temperature and salinity gradients, determined and manta ined by strong heat losses and river runoff.
The role played by the density compensation on the features of the WACC has been
elucidated trough sensitivity studies relative to the salinity and wind forcing. It has been found that, in absence of any salinity forcing, the WACC appears considerably weakened and the baroclinic component of the total velocity may reverse its direction.
Such result can be explained by assuming that the increase of density determined by the winter cooling of the coastal water is balanced (through a mechanism of density compensation) by the density reduction dependent on the fresh water inpu t (mainly originating from the river runoff). The reduction of the baroclinic horizontal g radient makes the the WACC in winter mainly wind driven.

OA3 Circulation and water mass transformation in the Mediterranean

Convener: Lascaratos, A.
Co-Convener: Crepon, M.

WEDDY INVESTIGATION IN NORTH-WESTERN MEDITERRANEAN

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The Weddy was found at the northern part of Algeria-Provencal basin during the 10th cruise of R/V "Akad.S.Vavilov", being a part of "THETIS-II" European project, in summer 1994, characterized by very low saline and temperature parameters (at least on 0.3 psu and 0.7 deg.C lower than in background waters of the same depths 200-700 m and ellipse shape with axis of 85 and 45 km).

The izopicnal analyzes of the potential temperature and salinity anomaly distribution in the Weddy and their geometrical parameters are proposed.

This Weddy residence time is possibly not very short: according to Millot C. and Jean-Luc private communications this structure can be identificated by French IR images during a long period of observation.

EXAMINING MESOSCALE CIRCULATION AND VERTICAL SHEAR THROUGH ISOPYCNAL MAPPING OF POTENTIAL VORTICITY.

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During the observational phase of OMEGA, an EU funded project under the MAST programme, high resolution hydrographic and current profiling measurements to 350 m water depth were made both at the western and eastern ends of the Alboran Sea. Both are regions of strong vertical shear. At the western end, Atlantic water inflow in the upper 100 m drives an anticyclonic gyre characterised by surface currents in excess of 125 cm/s. At a depth of 150 m the currents are less than 50 cm/s and at 250 m there is no evidence of anticyclonic circulation at all. The shape of the gyre is variable over periods of only a few days. Below a well defined halocline, 170 m deep in the centre of the gyre rising to ~50 m at the northern edge of the gyre, there is little isopycnal variation in stratification. At the eastern end of the Alboran Sea, upwelled Modified Atlantic Water along the Spanish coast and the variability of a second 'eastern' Alboran gyre form a complex frontal zone between the Alboran Sea and the rest of the western Mediterranean Sea known as the Almeria-Oran Front. Instability of this front to perturbations at the mesoscale (10-100 km) is clearly visible in satellite IR images. Additionally, there are large horizontal variations in stratification below the halocline and T/S profiles indicate a recirculation/transport of water from the east. We will contrast the physical processes in these two regions by mapping potential vorticity and its components on isopycnal surfaces.

A STUDY OF THE MEDITERRANEAN VARIABILITY USING TOPEX/POSEIDON & ERS-1 ALTIMETRY & ECMWF WINDS.

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P-Y.Le Traon (CLS, Space Oceanographic Division, Toulouse, France)

The Mediterranean variability appears as a combination of sub-basin scale gyres, mesoscale eddies and meandering jets, characterised by a large range of temporal scales. We investigate the topographic signature of this variability using TOPEX/POSEIDON (T/P) and ERS-1 altimetric data and its connection with wind forcing. A 4-year time series of T/P sea level anomaly allows us to recover major seasonal components and to observe strong interannual events. To take advantage from the frequent T/P sampling and the dense ERS-1 coverage, both datasets are merged over the period Oct 92 - Dec 93, via an objective analysis method. The combination results in a significant improvement of the mesoscale signal description. Coastal currents are recovered in the northern Western Basin, while propagating eddies are detected along the Algerian coast. We then compare the observed signals with wind stress. Using 3 years of ECMWF daily winds we analyse the correlations between atmospheric interannual events and sea level signals which display strong changes in shape, intensity or location from year to year. We then study the barotropic sea level response to the wind stress curl within the quasi-geostrophic assumption and taking into account bathymetry. Lastly, we investigate links between large scale wind action on gyres and mesoscale strutures, with the example of the Ierapetra gyre and of the Liguro-Provençal current, as well as the possible connection between wind stress curl and mesoscale activity at smaller spatial scales in the Tyrrhenian Sea.

EXPERIMENTAL STUDY OF THE STABILITY OF AN INTERMEDIATE WATER CURRENT

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In the 13 m diameter tank we study the stability of a flow of intermediate water. Before the intermediate water current is introduced, the two-layer system is in solid body rotation. It appears that the Ekman and Burger numbers of the incoming flow play a crucial role in the instability process. The phenomena is highly deterministic and, for decreasing Burger numbers, we observe (i) a stable current, (ii) cyclonic instabilities at the outer edge of the current, (iii) the formation of dipoles, either remaining attached to the current or periodically shed by the current and (iv) the periodical shedding of lenses similar to the meddies. When they appear, the dipole or the lenses, result from a baroclinic instability which always first manifests itself by a small vortex at the wall. This vortex grows first into a meander, then into a dipole or a lense. The locations where this occurs is very repeatable.
We checked that when the current is stable it is in geostrophic balance. We noticed that the Ekman pumping at the upper and lower interfaces of the current is responsible for a sizeable radial flux of momentum. We developped a theoretical model for the instability which matches with our observations. We got a huge data set of velocity and vorticity fields and radial density profiles of the flow for the various cases considered.

RESULTS OF THE FIRST MEDITERRANEAN MODELS EVALUATION EXPERIMENT (MEDMEX)

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MEDMEX group, E.U. concerted action MAS2-CT94-0107 (http://modb.oce.ulg.ac.be/MEDMEX)

The aim of the present work was to achieve an intercomparison of the existing models which are currently applied to the Mediterranean Sea. Intercomparison was not devoted to purely mathematical aspects, e.g. on turbulent closure schemes, or on a specific numerical aspect. A more general model test situation was chosen: the realistic and complex situation found in the Mediterranean circulation, were the first intercomparison experiment was devoted to the modelling of the seasonal cycle. Coarse grid (1/4°) models forced by perpetual year conditions based on monthly mean air-sea interactions allow to compare quantitatively and qualitatively the models ability to resolve this cycle. The models participating in the intercomparison (MOM, POM, GHER, OPA, MOMb) all used the same external forcings and resolutions. The presentation of the results will present the general model agreements on circulation patterns and fluxes through straits, but also some different representations of the water mass caracteristics after 15 years of integration. Some possible explanations of the models behaviour will be given.

ALTIMETER DATA ASSIMILATION AND SENSITIVITY STUDIES IN A PRIMITIVE-EQUATION MODEL OF THE MEDITERRANEAN

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The main aim of this work is the assimilation of altimetric data into a primitive equation numerical model for the whole Mediterranean. We start by making a climatological run in over ten years in order to have a steady initial state for the following runs. We then use high-frequency, realistic atmospheric forcing from ECMWF (European Center for Medium-Range Weather Forecast) for a two year run 1992-93. We compare these model outputs with TOPEX-POSEIDON altimetric data over the same period. Finally, we assimilate these data during 1993 using a statistical method based on vertical empirical modes and optimal interpolation. A similar method had previously been applied by Dombrowsky and De Mey (1992) in the North-East Atlantic in a quasi-geostrophic model. The vertical modes are calculated from model statistics during 1993, with ECMWF forcing. The assimilation results show that the $\frac{1}{4}°$ model has the ability to produce realistic circulation with some predictive capabilities in the 7-14 day range. Sensitivity studies have also been carried out, in particular to study the influence of ERS-1 data on the assimilation, the choice of statistical parameters, the localisation of empirical modes, the use of a smoother mode and the choice of forcing functions.

ANALYSIS OF MESOSCALE STRUCTURES IN THE ALGERIAN CURRENT FROM ERS-1 AND TOPEX/POSEIDON ALTIMETRIC DATA

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The most intense current in the Western Mediterranean basin is the Algerian current. Modified Atlantic Waters (MAW) flow along the African coast from the Alboran Basin to the Sicilia Strait. Satelite images have often shown a great spatial and temporal variability of the Algerian current. The formation of big anticylonic eddies and their interaction with the current is a knwon feature not well understood. In this work we analyze the observed mesoscale variability of conbined ERS-1 and TOPEX/POSEIDON altimetric data objectively mapped from October 1992 to December 1993. CEOF analysis show the spatially correlated signal between (0-15 E and 35-40 N) to be dominated by the first two modes. These two modes explain the 85 % of variance with 80 % in the first mode and a 5 % in the second mode. The second mode seems to be spatially representative of mesoscale structures with a temporal phase showing a 6 months periodicity. Finally, we have also applied a fuzzy Artmap neural network, to test the ability of these kind of techniques in identifying mesoscale structures, as an alternative to CEOF decomposition.

THE OPENING OF THE BLACK SEA: IMPLICATIONS FOR MEDITERRANEAN SAPROPEL FORMATION

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The opening of the connection between the Mediterranean and Black Sea as sea level rose above the Bosporus sill has long been associated with the formation of the most recent, Holocene, sapropel deposit (S1) in the eastern Mediterranean, but the mechanism has remained elusive. We present a model for the opening of the Black Sea, based on hydraulics arguments, which demonstrates that increased freshwater flux out of the Black Sea began 500 to 1000 years after sea level reached sill depth and that the time scale for the increased freshwater flux that drained the freshwater reservoir of the Black Sea is about 2,500 to 3,500 years. We argue that the increased freshwater discharge out of the Black Sea would lead to decreased deep water formation and higher productivity in the surface waters in the eastern Mediterranean, two conditions generally associated with sapropel formation. The delay in increased freshwater flux after the opening of the Black Sea and the period of increased freshwater discharge appear to match the onset and duration of sapropel deposits in the eastern Mediterranean.

A NUMERICAL STUDY OF THE INTERANNUAL VARIABILITY OF WATER-MASS FORMATION PROCESSES IN THE MEDITERRANEAN SEA

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Numerical experiments with a modified GFDL-MOM version are conducted to investigate the interannual variability of water-mass formation processes in the Mediterranean Sea. First, a set of calibrated bulk formulae of surface heat fluxes are defined for the period 1980-1988. An OGCM performance analysis to these different parameterizations shows that the set of calibrated bulk formulae can markedly improve the water-mass representation of the OGCM. Second, an analysis of the OGCM response to different atmospheric forcing frequencies (monthly versus 12-hourly) in the regions of water-mass formation events is conducted. Most of the experiments are able to simulate well the Levantine Intermediate Water (LIW) and Levantine Deep Water (LDW); however, the 12-hourly forced experiments (D-experiments) produce an LIW volume larger than observed. Only the D-experiments with Mellor-Yamada turbulence scheme are able to simulate the Western Mediterranean Deep Water (WMDW) deep convection. All experiments stress the importance of a correct simulation of the preconditioning phase for WMDW. This study confirms that the variability in the wind stress and heat fluxes can induce significant interannual fluctuations in the circulation and produce the water-mass formation events in the Mediterranean Basin.

MUSHROOM-LIKE CURRENTS (VORTEX DIPOLES) OBSERVATIONS IN THE ALBORAN SEA

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The circulation in the Alboran Sea is roughly formed by an eastward jet of Atlantic Water and two big anticyclonic gyres. Jet fluctuations and small mesoscale eddies can greatly modify this large-scale picture. We report here the observation of mushroom-like currents (dipole vortexes) from a series of infrered satellite images from June to October 1996. These mesoscale features are able to strongly interact with the Western Alboran Gyre (WAG). The formation of these structures seems to be related with local jet instability and local wind frocing. A first dipole structure was observed to form in the north-eastern side of the Alboran Sea and evolved from 24 to 26 June. The head of the vortex pair was formed by two eddies with a diameters approximately of 70 km. The dipole jet width was aproximately about 20 km. After two days of wesward motion the dipole collided with the WAG. Therefore, the thermal front was sharpened and the dipole was disipated at least its surface signature. A second dipole surely induced by wind forcing, produced a clear intensification of the Atlantic Water inflow through Gibraltar Strait. This dipole observed in October 6, was much more asimetric. The diameter of the anticyclone was 70 km. The cyclonic part was smaller with a diameter about 50 km. The observations suggest that these mesoscale features can affect the structure of the circulation of the Alboran Sea.

DOUBLE-DIFFUSION PROCESSES AND LIW CHARACTERISTICS IN THE ALBORAN SEA

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Double-difussion instabilities are characteristic small scale processes arising from the contrast between warm and salty water with colder and fresher environmental water. This kind of situation is commonplace in the path of Levantine Intermediate Water (LIW) through the Mediterranean Sea. To analyze the intensity and how these processes affect the LIW distribution in the Alboran Sea, we have analyzed 134 CTD profiles from the FE-92 spanish cruise. The zones where the LIW core shows highest gradients of salinity and potential temperature are the place where intense thermohaline exchanges exist between Atlanic Waters and LIW. We have found that the topography of LIW core is well correlated with the mesoscale circulation in the surface layer. The LIW core is practically constraint to flow between 200 and 600 meters of depth. The Turner angle shows a diffusive regime in the upper limit of the LIW core, and a salt fingers on its lower limit. Apparently LIW in the Alboran Sea has no longer a salt stock sufficient to maintain the salt fingers regime. On the other hand, the heat stock is still favourable for the diffusive regime.

ECMWF WIND STRESSES AND THEIR EFFECT ON THE TRANSPORT THROUGH THE MEDITERRANEAN STRAITS

D. Faggioli and V. Artale (ENEA-CRE Casaccia, Rome, Italy)

The role that the wind forcing plays on the Mediterranean Sea circulation it is very important, for investigates in detail its effect we use a numerical general circulation model (GFDL-MOM) forced with realistic wind data. The model is a primitive equation model with rigid lid and horizontal resolution of 0.25° x 0.25° and 19 levels in vertical.
In order to give an estimation of the temporal scales on which the wind stress acts we decided to consider the 1987-1994 ECMWF wind data set.
The preliminary analysis performed on this dataset shows the variability both in time and in space of the forcing factor.The effect of the sampling time of the forcing on the variability of the main structure of the circulation is considered in order to investigate the high frequency component induced by the wind field.
The study is focused on the transport through the straits of the Mediterranean Sea for studying in detail the flow variation with long temporal series of realistic wind forcing and the modification induced by strong temporal variability.
A comparison with experimental data relative to the same period was done for support the validity of the numerical simulation.

SIMULATION OF THE SYNOPTIC AND SEASONAL CIRCULATION VARIABILITY IN THE ADRIATIC SEA

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The baroclinic and barotropic circulation were investigated in the Adriatic Sea with several numerical models that employed horizontal resolutions ranging from 3-5 km. The model domain generally ended at the Strait of Otranto, except for the case of open boundary conditions (o.b.c.) that included a buffer zone south of the Strait. Other o.b.c. studied included flux relaxation and field specification from the output of basin-scale models. The atmospheric forcing was derived from prediction model outputs at 6-hourly intervals and .5 deg resolution, for the years 1992-1995. A strong synoptic event was observed in January 1993 when the circulation changed from a strongly cyclonic to anticyclonic in the northern end of the basin. On the average, the circulation was predominantly cyclonic in the southern sub-basin and more variable in the northern sub-basin.

ALGERS CRUISE, OCTOBER 1996: AN INTERDISCIPLINARY STUDY OF A MESOSCALE INSTABILITY OF THE ALGERIAN CURRENT (WESTERN MEDITERRANEAN SEA)

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MATER (MAss Transfer and Ecosystem Response) is theEuropean Union MAST 3 Mediterranean Targeted Project,and includes an interdisciplinary study of theAlgerian basin, a very poorly known marine region.The first MATER cruise in the area was ALGERS,carried out on board the Spanish R/V HESPERIDES from15 to 21 October 1996. A continuous remote sensingmonitoring allowed a detailed guidance of the in situsampling. A mesoscale meander of the Algerian currentwas developped near 1 E. It appeared like an usualcoastal anticyclonic eddy, with a well-markedsecondary cyclonic circulation. We spent all the time(the cruise was shortened for external reasons) tosample this structure exhaustively: ADCP, CTD andXCTD/XBT profiles, oxygen concentration, nutrientsand chlorophyll determinations, primary productivity,suspended particulate matter, radioactive tracers.Several satellite-tracked surface drifters were alsoreleased for a long term survey of the circulation inthe Algerian basin. The detailed analysis of allthese recorded variables will give, for the firsttime, a three-dimensional characterisation of thephenomenon and allow gaining some definitive answers.

LARGE SCALE VARIABILITY OF THE WESTERN MEDITERRANEAN OVER A SEASONAL CYCLE

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Thetis 2, funded within the MAST-2 program, was a pilot experiment for monitoring the Mediterranean at the basin scale. Carried over most of the year 1994, it has provided a unique dataset for the observation of both time and space variability of the western mediterranean basin. Seven moorings equiped with tomographic instruments were set around the western basin. Complementary to the moored array, an XBT line was performed twice a month along a specific section. As a first step toward data assimilation, we will examine the information content and consistency of the two datasets. The tomography data provides a time continuous constraint on the heat content integral over more than 10 sections. The XBT data describes, with fine vertical and mesoscale (25 km) horizontal resolution, the temperature structure of one of the tomographic sections. The informations contained in the tomographic integrals are combined and analyzed with a diagnostic inverse methods. The large scale component of the signal (over 200 km) is estimated with high temporal resolution. It is compared to the equivalent signal found in the XBT observations.

SEASONAL MODIFICATION OF THE MEAN CIRCULATION AT THE BLANES CANYON AREA, NW MEDITERRANEAN

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In the framework of a three-year study of the factors governing the mean circulation in the Blanes canyon area (NW Mediterranean), R/V Garcia del Cid performed a fine-scale hydorgraphic survey of the study domain in November 1995. CTD casts were performed with characteristic spacing of 7 to 15 km during the cruise. Current velocity measurements were obtained from ADCP records acquired both en-route and on-station and also through Lagrangian drifters released at selected points and further tracked via Argos. A multitemporal series of AVHRR images contemporary to the cruise was available for the study. Typical autumn oceanographic conditions (sinking pycnocline at 80-90 m depths, surface temperature changes by 0.5 degC in 2-3 days) were found during the survey. We compare the observed local water masses distribution and the mesoscale circulation against the mild-weather summer conditions encountered in June 1993. The role of the Blanes canyon as a "catchment" area for low-salinity waters advected from the Gulf of Lyons related to the formation of mesoscale anticyclonic eddies is examined.

DEEP WATER CHARACTERISTICS IN THE TYRRHENIAN SEA.

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Investigations effected during the past years in the Tyrrhenian Sea permitted a better comprehension of its deep circulation. Two Deep Water veins, of western and of eastern Mediterranean origin, respectively, were found to enter this basin. The Western Mediterranean Deep Water (WMDW) enters through the deepest part of the Sardinia-Sicily opening and can be discerned along the southern slope of the central chasm, at depths below 700m. It is characterized by relatively lower values of salinity and temperature. The second vein, which follows the same route as the LIW coming from the Eastern Basin, is observed near Sicily, close to the bottom. The high salinity and the low temperature make it denser than the Tyrrhenian water and hence, it sinks down to 1300-1800m of depth after entering the basin. Subsequent to a significant mixing with the resident water (WMDW), a well defined vein flows along the Italian Peninsula, between 1400 and 1800m of depth. This vein is subjected to lateral salt and temperature exchanges which could be a source for the maintenance of the step structures observed in the central part of the Tyrrhenian Basin. Finally, an outflow of modified Deep Water is observed along the northern slope of the Sardinia-Sicily opening. All the results evidence the central role played by the Tyrrhenian basin as the primary destination of the Eastern Mediterranean inflow and the tight connection of its circulation with the deep circulation of the Western Mediterranean.

REMOTE SENSING OF THE TRANSPORT OF BLACK SEA WATER IN THE NORTH AEGEAN SEA

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The transport of Black Sea Water (BSW) into the North Aegean Sea has been studied on the basis of NOAA-AVHRR, thermal satellite data during one year (March 1995-March 1996). It has been found that there is a seasonal transport pattern. During summer the transport seems to take place mainly south of the islands of Imvros and Limnos. The rest of the year the transport is mainly directed westwards passing between the islands of Imvros and Limnos and the heading towards northwest.

Extensive upwelling was found to take place off the Asia Minor coast south of the Dardandelles during summer/early autumn. BSW outflow is strongly interacting with this upwelled water and the BSW is thus difficult to distinguish. During the rest of the year BSW outflow was very distinct and of a jetlike nature.

Application of the Maximum Cross Correlation method for quantitative derivation of surface flow velocities using sequences of NOAA-AVHRR scenes was possible to carry out in a manual way. It was found that the derived surface flow vectors were of the order of 0.1 m/s and that satellite-derived flow patterns showed similarities with the general geostrophic circulation of the area.

RECENT DEEP WATER PRODUCTION IN THE AEGEAN: IMPACTS ON THE ABYSALL AND UPPER LAYER CIRCULATION OF THE EASTERN MEDITERRANEAN

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Major changes in the thermohaline circulation of the Eastern Mediterranean were observed during a basin-scale survey in 1995. They were caused by an intrusion of dense waters from the southern Aegean Sea. Hydrographic profiles, nutrient data and transient tracer data are used to quantify the Deep Water formation rates and to describe the changes in the abysall circulation and the intermediate layers. The intrusion of Aegean waters at the bottom of the Eastern Mediterranean resulted in an uplifting of mid-depth waters effecting the water column above 1400m up to the horizon of the Levantine Intermediate Water. The effects of this uplifting in relation with changes in the salt balance, impacts to the Deep Water formation in the Southern Adriatic and the Western Mediterranean and changes in the nutrient levels in the upper layers are presented.

A BOX MODEL STUDY OF THE MEDITERRANEAN THERMOHALINE CIRCULATION.

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In this study we investigate the existence of possible multiple equilibria and/or limit cycles of the Mediterranean thermohaline circulation. A simple 6 × 4 box model of the Mediterranean basin is formulated, taking into account the competing roles played by the thermal and haline forcing along the longitudinal direction of the basin. Within the model, individual boxes are connected by horizontal/vertical advection and mixing. In particular horizontal advection of properties is parameterized as being proportional to the hydrostatic pressure gradient while convective overturn is treated as a vertical diffusion process. Forcing is in the form of a Rayleigh boundary condition for temperature and a flux boundary condition for salinity. The model's configuration in vertical (four distinct boxes of fixed volume each) distinguishes between the three major water masses of the basin i.e. Atlantic waters, intermediate (LIW) and deep waters. The main body of the basin is divided into three subsystems namely the Western Mediterranean, the Ionian and the Leveantine basins while we allow also for the existence of deep and intermediate waters formation areas (Lions Gyre, Adriatic and Rhodes Gyre regions).
Preliminary results of experiments where a stochastic component is added to the freshwater flux, show the existence of limit cycles with periodicities of approximately 500 years.

THERMAL VARIABILITY OF THE SICILIAN UPWELLING

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The preliminary analysis of the thermal characteristics of the Sicilian upwelling based on the satellite AVHRR IR weekly data published in the SATMER Bulletin (September 1983 - November 1988) showed that though the upwelling is persistent throughout the year, it has an interannual, seasonal and short-time (one week) variability, induced by the variability of the wind field. In 85% cases, upwelling occupies more than half of the length of the southern Sicilian coast with a mean off-shore width of 20-40 km. The temperature contrast of upwelled waters with surrounding ones reaches 3C in August-September and absolutely disappears in March-April. It was found that upwelling filaments sporadically start from the West and East sides of the southern coast of Sicily. Totally about 50 distinct filaments were detected and their spatial and thermal characteristics were analysed. Though the mean length of filaments is 150-200 km off-shore, they can reach 500 km length with velocities up to 50 cm/s.

INTERANNUAL VARIABILITY AND LONGTERM TRENDS IN WESTERN MEDITERRANEAN WATERMASSES

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Historical temperature and salinity measurements in the Western Mediterranean Sea collected from various sources have been used to derive anomalies from longterm monthly values. The temperatures of the Levantine Intermediate Water show deviations of $\pm 0.15°C$ from the average temperatures on time scales of 3 to 10 years. Longterm trends are not found in the Intermediate Water. Temporal and spatial scales of the variability are examined and used to evaluate possible sources.
Longterm trends are found in surface and deep water mass characteristics. The vertical and horizontal distribution of the trends suggest that the well-known deep water trends in the Western Mediterranean are caused by a reduced freshwater input into the Western Mediterranean rather than into the Eastern Mediterranean. Longterm variability found in historical precipitation and river-runoff data is able to explain most of the surface trends.

SEASONAL CYCLE OF A COHERENT EDDY IN THE EASTERN MEDITERRANEAN.

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We monitor the signal of the Ierapetra anticyclonic gyre, the strongest mesoscale feature in the Mediterranean, for a period of three years with weekly SST maps. The life-cycle, the seasonal and interannual variabilities of the gyre are studied. Results reveal a clear annual cycle, identifying a steady pattern in the eddy's formation-deformation processes. For three consecutive years, we witnessed the gyre's formation occuring in late summer-early autumn, preceded by the spreading of warm African waters to the north, during summer, and followed by a period of total absence of any surfacial indication that the eddy exists. Interannual variabilities were observed, referring to shape, size and formation position.
Cross-referencing of previous notices of Ierapetra gyre partly supports our results but, furthermore, reveals the possibility of a sub-surface existence of the anticyclone during periods that bear no SST signal in our images.
While investigating for a generation mechanism, we considered some theories that connect the eddy with either (a) the Etesians wind system, suggesting the creation of lee vortices past a three-dimensional obstacle (Crete), or (b) the vortex creation due to the wake flow of a current. Both theories appear to be plausible but unquestionably require a further, more detailed, examination.

A MIXED LAYER STUDY IN THE THE CENTRAL MEDITERRANEAN SEA (SICILY CHANNEL AREA)

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In the research project that we are carrying out on the study of the physical and biochemical interactions in representative areas of the Mediterranean, the seasonal structure and dynamics of the mixed layer in the central part of the Mediterranean sea (Sicily channel area) were studied with the one dimensional version of the Princeton Ocean Model. The effect of the external forcing variability with idealised (sinusoidal) forcing functions (wind-stress, heat flux and surface salinity) was studied in order to analyse the response of the model under different forcing conditions. The variation of the limits of the wind stress and heat flux functions leads to a variation in the depth of the summer thermocline and the winter convection, this is generally in agreement with experimental data of the Sicily Channel area. The yearly variability of the mixed layer follows the yearly variation of the vertical eddy diffusivity and two particular mixing regimes have been identified at the end of May with two maxima separated by a transition zone of weak mixing which coincides with the base of the mixed layer.

A combined use of ERS and TOPEX/POSEIDON data to study the mesoscale dynamics in the Mediterranean Sea

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TOPEX/Poseidon and ERS-1 altimeter data have successfully been used to investigate the seasonal and year-to-year variability of the Sea Level and eddy statistics in the Mediterranean Sea. The mesoscale field described by TOPEX/Poseidon and ERS-1 revealed a strong, but sub-basin dependent, seasonal contribution to the total variance of the field. Year-to-year variations are also evident in terms of both intensity and size of the main mesoscale features. The EOF analysis applyed to both data set allowed to confirm and quantify the importance of the seasonal and interannual signal. Cross-over analysis indicated the existence of a meridional transport of eddy momentum away from the Algerian Current due to the northward migration of mesoscale eddies. A comparison between mesoscale features detected by the the two altimeters and contemporaneous features observed using Sea Surface Temperature maps obtained from AVHRR data definitively proves the direct relation between sea level anomalies and Mediterranean eddy field.

ON THE EFFECT OF DIFFERENT WIND STRESS CLIMATOLOGIES ON THE THERMOHALINE CIRCULATION OF THE MEDITERRANEAN

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An important component of the ocean circulation is that driven by the atmospheric wind forcing. Most ocean models use wind stress climatologies derived from one of two sources: analyzed output of numerical weather prediction models and in-situ observations. It has been shown previously that the large differences that exist in both structure and magnitude between the different climatologies can produce significant differences in the resulting circulation of an ocean general circulation model. Here, we examine in detail the response of a general circulation model of the Mediterranean to three different wind stress climatologies (NMC, ECMWF and SOC). In particular we examine the changes in the intermediate water pathways and the role this plays on the large scale thermohaline circulation. We also examine the effect the different wind stress climatologies have on the surface fluxes diagnosed from the model.

FLOW INSTABILITIES IN THE STRAIT OF SICILY

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We present results of a numerical model investigating the stability of currents in the Strait of Sicily. The model domain is a channel with different bathymetries. As initial conditions we use summer and winter climatological density fields. For all bathymetries the channel flow is found baroclinically unstable comprising most unstable waves of 100 and 133 km wavelength in summer and 67 km in winter. A parabolic bottom profile instead of a flat bottom stabilizes the flow in the north and leads to further destabilization in the south. Inclusion of two shallow shelf sea areas leads to a deflection of the summer flow both in the Atlantic Water and the Levantine Intermediate Water range and to the generation of stationary eddies.

Waves of similar wavelength as predicted by the model were identified in satellite images. Records from moored current meters support enhanced flow instability on the African side of the Strait. The stationary eddies in the Atlantic Water range are found to be consistent with climatology and previously known patches of low sea surface temperature downstream of the shallow sea areas.

SEASONAL VARIABILITY OF THE ALGERIAN/PROVENÇAL BASIN CIRCULATION FROM HISTORICAL DATA.

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The Algerian/Provençal basin and the Sardinian Channel are regions of intense dynamical processes both in the coastal and in the open ocean areas whose driving mechanisms and response to the atmospheric forcing are not yet well known. The analysis of mean temperature and salinity profiles and of high resolution maps, obtained using MODB (Mediterranean Oceanic Data Base) historical hydrological data set, revealed the presence of two LIW branches off the western side of Sardinia, into the Algerian/Provençal basin: northward along the Sardinian coast, westward south-west off Cape Teulada. Another branch, along Algerian coast, shows the highest salinity and temperature maximum in the subsurface with the possibility of compensation effects in the density equation. The analysis also revealed interesting seasonal dynamics of mixing in the Sardinian Channel and the possibility of horizontal eddy dispersion due to the instability of the LIW current turning northward after Cape Teulada. The space and time scales of the structures will be also assessed from the NASA/JPL long satellite images time series. The atmospheric forcing parameters will be taken from the analysis of ECMWF (European Centre for Medium Range Weather Forecast) data. This background information will be useful for future design of operational monitoring networks in the region.

A MODEL OF THE ALBORAN GYRE

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The question of what happens when anomalous water enters an ocean via a zonal channel is addressed analytically using a reduced-gravity nonlinear model, with application to the strait of Gibraltar and the penetration of Atlantic water into the Mediterranean. The traditional view is that, due to the Coriolis force, such an anomalous eastward flowing current turns to the right (looking offshore) and forms a boundary current that flows southwards. In this scenario, a front (corresponding to a surfacing interface) separates the oceanic and the anomalous water.
Integration of the steady inviscid momentum equation along the boundary gives the long-shore flow-force and shows that such a scenario requires the presence of an eddy trapped at the mouth of the channel, featuring the Alboran gyre. The order of magnitude for this eddy can be calculated: it involves a *new length scale* $R_d/\epsilon^{1/6}$ (where R_d is the parent current Rossby radius and $\epsilon = \beta R_d/f_o$) which is *greater* than that of most eddies.
Numerical experiments confirm the process. They show that after an adjustment period, a final steady state is reached involving the trapped eddy mentioned above.

NUMERICAL EVIDENCE OF WIND-DRIVEN PLANETARY WAVES IN THE WESTERN MEDITERRANEAN

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It is interesting to inquire whether the Rossby dynamics, which has proved so important in accounting for the variability of large oceans, plays some role also in the Mediterranean Sea, i.e. in a situation in which the scales and the topography are so specific. In a previous study the possible existence of topographic Rossby modes in the Strait of Sicily was demonstrated. In this communication results of numerical studies are presented showing the possibility of the existence of planetary Rossby waves in the Western Mediterranean Sea.
First, the effect of idealized bathymetries on wind-driven planetary waves is analysed in the framework of a box model. For strong topographic gradients covering a large portion of the total basin area (like in the Central Ionian or the Tyrrhenian Sea), the existence of planetary waves is found to be prevented by the overwhelming action of the topographic steering. However for a situation more similar to that of the Algero-Provençal basin, where a large nearly flat-bottom area is present, planetary waves could in principle be excited.
Secondly, the results of a barotropic circulation model of the Mediterranean forced by the 1980-88 NMC winds confirm this hypothesis. The analysis of the residual currents related to the beta-effect shows clear events of westward propagating planetary waves confined in the Algero-Provençal basin and originating from large wind anomalies, with current velocities of up to 30% of the total.

ON THE FORCED INTERANNUAL VARIABILITY OF THE MEDITERRANEAN SEA

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The year to year differences in the circulation in the Mediterranean Sea are explained by anomalies in both wind and heat fluxes. The GFDL-MOM is used to simulate the circulation structure for a 9-year study period, from January 1980 to December 1988. It is found that the regular occurrence of the seasonal cycle is halted by large scale wind stress anomaly events occurring during the winter time.
Large fluctuations in the westward volume transport at Sicily are found to be correlated to wind stress anomalies. The baroclinic and barotropic components of the westward volume trasports are found to contribute to the overall westward transport for 1/3 and 2/3 respectively. The low baroclinic westward transport estimates are found to be in agreement with observations. It is argued that the ocean can memorize the winter anomalies events up to few seasons, thus changing the response to atmospheric forcing in the upcoming seasons depending on the state of the circulation during the previous season.

THE ROLE OF WINTER INTERMEDIATE WATERS IN THE CIRCULATION OF THE BALEARIC SEA

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We have used the Modular Ocean Model (MOM) to investigate the influence of the Winter Intermediate Waters (WIW) on the density-driven circulation in the Balearic Sea, and more particulary on the exchanges through the Ibiza channel. On the basis of *in situ* observations, numerical simulations have been carried out with different initial and boundary conditions including or not WIW north of the Ibiza channel and an inflow of Modified Atlantic Waters (MAW). The results obtained from the different numerical experiments evidence the sensitivity of the circulation in the southern Balearic Sea to the successive configurations. We have found that the existence of WIW strongly deflects the southward Northern Current away from the slope towards the Balearic slope, reducing the transport through the Ibiza channel during a few months. Even more, presence of WIW can almost block the northward MAW inflow through the Ibiza channel if the later is present. Concluding, WIW seem to have a relevant role in the circulation of the Balearic Sea with a likely major impact on the ecosystems of the Balearic and continental shelves. This study is a contribution to the MAST/MATER program.

THE SENSITIVITY OF THE MEDITERRANEAN THERMOHALINE CIRCULATION TO VERTICAL DIFFUSION IN MOM MODEL

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A derived Cox model applied to the Mediterranean Sea is used to study the thermohaline circulation in the Mediterranean Sea. A sensitivity study of the Mediterranean thermohaline circulation vs. the vertical diffusivity shows an inverse proportionality between the tracer vertical diffusivity and the strength of the thermohaline cell. The averaged mass transport at the Gibraltair and Sicily straits depends on the vertical diffusivities and assumes respectively the values of $0.97 < Q_g < 1.19$ and $1.36 < Q_s < 1.63$ $[Sv]$ for K_z ranging to 0.0-1.0 cm^2/sec. This inverse proportionality is rationalized studyng the surface air-sea buoyancy fluxes as a function of a surface water density. This allowed to evaluate the annual rate of Levantine Intermediate Water formation with relation to the different role of the vertical mixing in the eastern and western sub-basins. A synthetic budget scheme is performed to relate the Levantine surface source with the Gibraltair outflow.

LAGRANGIAN OBSERVATIONS OF THE ALGERIAN CURRENT.

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The Algerian Current flows along the Algerian coast in a turbulent way, often showing a broad spectrum of instabilites. In winter and summer one of the most common features, several times reported in the literature, is the formation near 0-1o E of mesoscale events which mainly appear as anticyclonic eddies, with several tens of km in diameter propagating downstream at few km/day. Some of these eddies can have lifetimes larger than several months. The processes leading to the generation of these structures are not well understood and baroclinic instability probably plays a major role. With the purpose of gaining insight in their dynamics, the ALGERS/MATER experiment was recently carried out, combining observations from 18 ARGOS buoys with NOAA infrared imagery, ADCP and CTD ship measurements. The NOAA infrared images show the existence of energetic mesoscale variability, but the most important is the formation of anticyclonic eddy. The buoys were launched across and upstream such an event. Their trajectory describe the character of the Algerian Current and catalogue some typical flow structures observed on the satellite images. The time and space scales deduced from the trajectories are compared with those found in laboratory and numerical experiments.

QUASI PERMANENT FLOW STRUCTURES IN THE SICILIAN CHANNEL

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We present results of three surveys in the Sicilian Channel in Nov 94, Oct 95 and Aug 96. The measurement data of temperature/salinity probes, on-board and sea-bottom deployed current profilers, satellite tracked Lagrangian drifters and sea surface radiometry result in a consistent picture of the prevailing water mass distribution and circulation pattern in the area between the Sicilian coast and the Tunisian shelf. The Levantine Intermediate Water of the Ionian Sea is diluted over the eastern sill and on the shelf. In the salinity range 38.71 to 38.76 it fills the basins below 200 m. Modified Atlantic Water enters the Strait of Sicily at the African coast and comes to rest near Cap Bon. The main transport of surface water is through the frontal jet that is guided by a cyclonic eddy sitting on the Adventure Bank slope NE of Pantelleria.

OBSERVATIONS OF TRANSPORTS AND HORIZONTAL AND VERTICAL SHEARS IN THE STRAIT OF GIBRALTAR

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In April 1996, a pilot experiment was conducted in the Strait of Gibraltar, in order to obtain detailed information on the structure of the flow through the strait. The objective was to be able to describe and quantify the vertical and horizontal shears of the flow in the eastern part of the strait. This helps dynamical insight and allows design of a suitable observing system for long-term transport monitoring. The results presented here come from a variety of techniques. Three moorings had been deployed across the strait to provide the long-term temporal information. Vertical shears were observed with an ADCP system lowered from the ship, and horizontal shears were provided from a hull-mounted ship ADCP. In addition, several acoustic approaches were tested, which employed acoustic transmissions across the strait, in order to integrate the (lower-layer) flow horizontally. Analyses are presented, which compare and merge the various types of data, in order to arrive at improved transport estimates and to make recommendations on long-term monitoring.

HYDROGRAPHY OF THE EASTERN ALBORAN SEA OBSERVED DURING OMEGA

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During the second cruise of the OMEGA project the towed CTD SeaSoar was deployed to survey the upper 350m of the water column in the Eastern Alboran Sea. Fluorescence, optical back scatter and light were measured along with conductivity and temperature with an effective along track resolution of 4km. The combined data sets have enabled a detailed description of the different surface water types and the fronts that separate them. Atlantic water enters the Alboran via the straits of Gibraltar and circulates around a system of gyres before forming the Algerian current. The edge of the eastern most gyre forms the Almeria Oran front. Within the gyre relatively warm fresh water overlies cooler saltier Levantine intermediate water. Between these is a transitional layer about 100m deep. To the east of the Almeria Oran front the transitional layer reaches the surface. The large density gradient across the front results in a strong geostrophic flow. The highest levels of fluorescence and back scatter were found in this area. South of Cartagena a second front separates the transitional waters from the relatively warm and salty Mediterranean surface water which are also marked by very low fluorescence and back scatter. However, compensating changes in temperature and salinity resulted in a very small density change across this front. In this area a temperature minimum layer was observed to lie above the Levantine water.

STRAITS OF SICILY WATER MASS STUDIES

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We have derived a water mass model for the Straits of Sicily, based on 1994 and 1995 cruise data.The model consists of seven water masses,suggested by the shapes of the vertical temperature and salinity profiles.Frequency of occurrence and objective analysis of the model parameters was performed.A core of Atlantic water mass below the surface was outlined by a cusp shaped minimum salinity distribution.It was caped by an upper layer above and a mixed region below.The frequency of occurrence depth of the Atlantic water core center was around 70 meters, suggesting a shallow upper ocean location for the inflowing Atlantic water.The salinity distribution center was at 37.4 ppt.On the southeastern Sicilian shelfbreak,the oceanc currents were monitored with moorings.The locacation was in the area of the previously observed Maltese front.Some of the moorings showed the presence of flow associated with the Atlantic Ionian Stream.Surface drifters released during the cruises collaborated this.The temporal and spatial variabilities of the volume flows and domain boundaries associated with the major water masses is studied via high horizontal resolution,5km, and 64 level ocean model using 6-hour forcing and an embedded mixed layer.

OA4 The low-latitude oceans

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CFC DISTRIBUTIONS IN THE WESTERN TROPICAL ATLANTIC DURING ETAMBOT CRUISES (1995 - 1996)

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CFC analyses have been performed together with L-ADCP current measurements, during September 1995 and May 1996 ETAMBOT cruises, between the south american coast and the Mid Atlantic Ridge, in order to describe the deep circulation variability inside the Deep Western Boundary Current.
At the UNADW level, the CFC distributions show that one branch of the recirculation occurs just north of the Ceara Rise, when a second branch is flowing from the South along the eastern side of the Ceara Rise. This scheme seems to correspond to the general pattern observed in the area.
At the LNADW level, the recirculation pattern does not seem permanent : CFC concentrations increased between September 1995 and May 1996 and the circulation pattern (L-ACDP measurements) has considerably changed.
On the May 1996 CFC distribution, along the 7°30N section, the intrusion of a CFC signal below 2000 m depth seems to be linked to the intensive deep convection which occurred before 1989 in the Labrador Sea. In addition, the 35°W CFC distribution reveals a very particular pattern compared to previous distributions.

AN ANALYSIS OF ALTIMETRIC AND MODEL RESULTS IN THE TROPICAL ATLANTIC

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Four years (1992-1996) of TOPEX/Poséïdon altimeter sea level anomalies have been processed over the tropical Atlantic ocean. These data are analysed in term of sea level variability and mass and heat transports together with the results of a non-linear primitive equation model. The emphasis is particularly on the North Equatorial CounterCurrent and on the Gulf of Guinea regions.

A SYNOPTIC STUDY OF THE UPPER LAYER CIRCULATION IN THE WESTERN TROPICAL NORTH ATLANTIC.

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From six cruises, spanning from August 1989 to September 1991, the currents, transports and water masses of the upper layers. from the surface down to the σ_θ=26.75 isopycnal, in the western tropical north Atlantic are described. Three cruises were carried out in August-September, two in January-February and one in June. During these six cruises, the North Brazil Current retroflection is always present, and the southern hemisphere origin waters of this flow feed the North Equatorial CounterCurrent and North Equatorial UnderCurrent system, which are also observed during the six cruises, in agreement with climatology. These two last currents are also fed with North hemisphere waters, through a southward recirculation of part of the North Equatorial Current,and through a Western Boundary UnderCurrent, flowing southward off the coast. For each period of the year, cruise measurements exhibit very different circulation structures. This indicates that the annual cycle is strongly affected by a short time scale variability which sometimes masks the annual signal. This variability is responsible for the different features of the countercurrents, as the NECC and NEUC appear sometimes superimposed at the longitude 44°W. This feature seems strongly linked to the presence of NBC retroflection eddies.

INDONESIAN THROUGHFLOW: SEASONAL VARIABILITY OF THE WATER MASS COMPOSITION BETWEEN AUSTRALIA AND INDONESIAN ISLANDS

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Seasonal variability of the water masses in the Indonesian throughflow entering the Indian Ocean is investigated by using a multiparametric analysis based on data collected in the frame of the Java Australia Dynamic Experiment program (JADE) performed during two opposed seasons in august 1989 and february-march 1992. Tracers selected are the potential temperature, salinity, oxygen and nutrients. Six sources are identified: the Subtropical and Central Indian Waters (STIW, CIW), the Antarctic Intermediate Water (AIW), the Subsurface and Intermediate Indonesian Waters (ISW, IIW) and the North Indian Intermediate Water (NIIW). The results show little variations on the quantitative Indonesian waters distribution but important modifications characterize the waters coming from Indian Ocean. Compared to the southern monsoon, the northern monsoon appears to favour the NIIW input towards the Indonesian archipelago and lowers southern sources (STIW, CIW and AIW) contribution to the north-west Australia. A detail study of the NIIW flow along the Sumatra and Java coasts toward Indonesian straits will be presented.

SEASONAL CYCLE OF HEAT TRANSPORT IN THE EQUATORIAL TO SUBTROPICAL ATLANTIC OCEAN

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On seasonal time scales at mid latitudes, one expects a local balance between variations of net surface heat flux and rate of change of heat content, while at low latitudes one expects an advective balance between variations of heat transport and rate of change of heat content. We are interested in the transition between these two regimes: where and how is it taking place? Heat transport can vary because of variations in Ekman transport and/or variations in the geostrophic flow as fast baroclinic waves of the equatorial wave guide modify the zonal structure of the stratification. In the northern hemisphere the North Equatorial Countercurrent has been described as a barrier to seasonal heat transport: what then happens at similar latitudes in the southern hemisphere? These questions are addressed with the help of a numerical simulation. The seasonal cycle of the model heat transport and of its Ekman and geostrophic contributions are studied as a function of latitude, and the respective roles of the wind and of the net surface heat flux in inducing variations in thermocline slope are investigated.

Mesoscale Deep-Water Dynamics and Interaction with Upper Layers in the Central Basin of the Indian Ocean

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The studies were carried out on the basis of 4-month measurements of temperature and currents on subsurface buoys in the deep Central Basin of the Indian Ocean from October, 1995, to January, 1996. Current meters were placed at 5 levels from the surface to the bottom layer. The stratification was studied from repeated CTD profiles upto the bottom. Variability of mean values and corresponding RMS deviations as well as spectral energy maxima in subinertial to synoptic scale indicated various degree of contribution in the total circulation within the water column in different levels and provided reconstruction of their interaction. Time evolution of tidal and associated high frequency internal waves was considered. Features of water mass transport in the near-bottom and upper layers and contribution of internal wave and synoptic components in it during the fall and winter seasons were estimated.

DEEP MIXING IN THE EQUATORIAL INDIAN OCEAN

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Mixing intensity in the abyssal equatorial Indian Ocean is inferred. Velocity, temperature and vertical sheer spectra are calculated from time series of moored ADCP, current meter and temperature data (WOCE Array ICM-8). Vertical displacement wavenumber spectra are determined using CTD data from a five times repeat section along 80.5 E. Dissipation rates and time scales for unstable conditions found in CTD profiles are presented. The results are compared to mid-latitude values and indicate enhanced mixing within the equatorial wave guide. To quantify the tidal contribution, a harmonic tidal analysis over a 12 month period using more than 40 independent depths from the equatorial mooring and 20 depths from off equatorial moorings is performed. The baroclinic tidal energy of the M2 and K1 constituent is determined.

VERTICAL STUDY OF AN OGCM: COMPARISON WITH LINEAR SIMULATIONS

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We investigate the vertical sructure of the variability in the equatorial Pacific in 1985-1994 based on an Ocean General Circulation Model and a linear model. We first solve the vertical structure differential equation at each grid point and time step of the OGCM simulation and investigate how the vertical modes vary in space and time. Contributions of baroclinic modes to surface zonal current and sea level anomalies are derived. We find comparable contribution of the first two modes with different spatial distribution in the equatorial wave guide. Third and fourth modes exhibit variability peaks in the east and in the westernmost part of the basin. High-order modes variability is concentrated near the dateline where we find maximum in zonal wind stress variability. We compare this structure with the one of multi-mode linear simulations with the projection coefficients and phase speeds derived from the OGCM simulation at various longitudes. For the first two modes, the comparison with the OGCM vertical decomposition shows a good agreement for the magnitude of the anomalies. Introducing a zonal discontinuity in the stratification for the linear simulation changes considerably the distribution of energy in higher modes. In particular the third mode is closer to the one found in the OGCM simulation. The two simulations reveal that in addition to the first mode forced equatorial Kelvin and Rossby waves earlier found in the data, higher modes forced waves should also be observable. However the analysis of the Kelvin and Rossby components of the signal indicates limitations in interpreting the OGCM decomposition strictly as long equatorial waves.

REMOTE FORCING OF THE SOMALI CURRENT

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Energetic low-frequency planetary waves in the western Arabian Sea during the Southwest Monsoon have been detected in current records from moored instrumentation and in TOPEX/POSEIDON altimeter data. The dominant signal has a period of 40 days and appears to be generated in the central Arabian Sea with the onset of the summer Findlater Jet. The impact of these waves on the Somali Current, in particular on the breakdown of the two-gyre system in the late monsoon phase, is discussed.

SEASONAL TRANSPORT VARIABILITY OF THE DEEP WESTERN BOUNDARY CURRENT IN THE EQUATORIAL ATLANTIC

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Current and transport fluctuations of the Deep Western Boundary Current (DWBC) at annual and semiannual periods were studied in the western equatorial Atlantic. Moored current meter records at 44°W from three annual deployment periods were supplemented by current profiling sections along 44°W and 35°W. The approximately 100 km wide DWBC at 44°W, just north of the equator, followed the topography, and the close agreement between the mean current direction and the direction of maximum variance indicated that the DWBC variability near the equator was mainly due to pulsing rather than meandering. The mean transport of upper NADW was 13Sv. Estimates for two different years were thereby in close agreement, namely at 12.4 Sv and 13.6 Sv. The DWBC transport showed a definite seasonal cycle, ranging from less than 7 Sv during September/October to about 25 Sv during January/February. Annual and semiannual transport harmonics had similar amplitudes, at about 6 Sv each, and together they explained about two thirds of the total transport variability. After crossing the equator, the DWBC splits into two cores, and the major flow along a chain of seamounts near 3.5°S, west of 35°W revealed similar magnitudes and phases of the transport variability.

HYDROLOGY AND CURRENTS IN THE WESTERN TROPICAL NORTH ATLANTIC AS OBSERVED DURING ETAMBOT.

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As part of the ETAMBOT program, two cruises have been carried out in the western equatorial Atlantic in September 1995 and April-May 1996. The cruises tracklines consist on three sections, along 7°5N from Cayenne to 35°W, along 35°W till 5°S and, inside this triangle, a diagonal section crossing the Ceara Rise, off Brazil. During both cruises, direct current measurements from the surface to the bottom have been performed with an Acoustic Doppler Profiler attached to the rosette (L-ADCP). First treatements of current data show the presence of the Deep Western Boundary Current (DWBC) on the three sections, trapped to the coast, between 1000 m and 2500 m depth. The core of maximum velocity is found at 1700 m. There is no branching of the DWBC at the equator-35°W in April-May 1996, while western drift is observed at 1700 m. The velocity and transport of the DWBC is maximum on the diagonal section at 45°W-0.30°N. On this section, juxtaposed to the DWBC and south of the Ceara rise, an opposite westward current of the same magnitude and thickness is observed. Further analysis of tracers and hydrological measurements should allow to determine if this current is a recirculation of the DWBC. The DWBC exhibits a strong time variability, as its zonal velocity component increases of 30 $cm.s^{-1}$ in one month interval off French Guiana during the second cruise.

THE CIRCULATION OFF THE SOMALI COAST IN SUMMER '95: COMPARING OBSERVATIONS WITH MODEL RESULTS

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Several shipboard measurements, mooring data, SST from AVHRR satellite sensors, and the output of the Semtner/Chervin 1/4°-model have been compiled to get an in depth view of the evolving current system off the Somali coast during the summer of 1995.

Every year during southwest monsoon the development and movement of the so called 'Great Whirl' appears as a remarkable current pattern in the region off the Somali coast. The current structure of the Great Whirl has been reconstructed from its stage of development in May 1995 up to its final collapse late in the year.

The passage between Socotra and the African continent has been found to have a substantial annual-mean transport to the north. It has been investigated how the shift of the Great Whirl to the north influences the throughflow rates of this passage.

The cold wedges of upwelling water at the southwestern and northwestern rim of the Great Whirl seen in SST maps are well developed in the Semtner/Chervin model; however, the southern wedge and the associated separation of the Somali Current from the coast appear further to north in the model compared to ADCP and SST observations.

TROPICAL ATLANTIC OCEAN INTERMEDIATE AND DEEP CIRCULATION OBSERVATIONS AND ISSUES

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Results from hydrographic, float and current meter measurements at intermediate and deep levels in the western tropical Atlantic over the past decade are summarized, with an emphasis on the "mean" circulation, but including secular and annual signals. In consideration of how decadal/interdecadal/centennial oscillations of the thermohaline overturning system may work within the climate change context, consideration of the cross - equatorial flows between North and South Atlantic is needed. Evidence of the "difficulty" deep flows encounter in simply crossing the equator is shown, as well as time-series measurements suggesting coordinated seasonal cycles of deep and bottom water flow elements at and near the equator. This seasonal modulation of flow at depth impacts experimental design, but is also of interest for cross equatorial flow dynamics. Looking towards the future, note is taken of a significant transient in the Upper North Atlantic Deep Water presently invading the subtropics, induced by Labrador Sea Water source changes of the past decade. This perturbation is destined to reach the equatorial western boundary in the next decade and may provide a naturally caused transient "experiment" on the cross-equator / along-equator flow system, potentially illuminating the equatorial dynamics at mid-depth.

SEASONAL VARIATIONS OF MASS AND HEAT IN THE INDIAN OCEAN ESTIMATED FROM A REDUCED GRAVITY THERMODYNAMIC MODEL AND FROM OBSERVATIONS.

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A 2 and 1/2-layer model forced by climatological fluxes is run to simulate the physics of the upper Indian Ocean. Observations (hydrographic profiles over 1980-1995 derived from Smith, 1995) provide climatological data sets which are used for comparison and analysis of the model simulations. The change rate of heat content in the upper ocean over 400m compares well in amplitude and phase with the simulated one. The largest discrepancies show up on the eastern side of the equator, with changes of $200W/m^2$ for the data and $50W/m^2$ for the model, and in the western region, at the center of the cyclonic gyre south of the equator ($50W/m^2$ and $200W/m^2$, respectively). Averaged zonally, the meridional heat transport calculated from hydrographic data and from the model air-sea fluxes agrees to some extent with the simulated one. The phase is particularly well reproduced by the model. Between May and October, the model simulates a southward cross-equatorial heat transport of 1.3 PetaWatts (PW), and during the rest of the year, the northern ocean replenishes its heat content at a rate of 0.9 PW. The corresponding figures for the observed estimates are 0.9PW and 0.5PW respectively. The possibility that the model data discrepancies be due to data errors is being examined with the TOPEX sea level 4-year data set and the FSU air-sea flux climatology.

ON VERTICAL STRUCTURE OF LOW FREQUENCY CURRENTS IN THE TROPICAL NORTH PACIFIC AND THE TROPICAL AND SUBTROPICAL NORTH ATLANTIC

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There were analysed the low-passed current meter records obtained from long term measurements at various depths on moorings in the deep-water regions of the "Abyssal" (1984-89), "DOMES" (1975-76), "Polygon-70" (1970) and "POLYMODE" (1977-79) experiments. In the region of the "Abyssal" experiment the low-frequency currents were shown to have a three-layer vertical structure, because they were caused by nonstationary disturbances of various origin in the layers selected (0-200, 300-2000, 3000-5000m). Besides a surface maximum and a bottom minimum (which corresponds to the 5000 m depth) the averaged over all data vertical profile of kinetic energy of the regional low-frequency currents has a subsurface (200 m) minimum and an intermediate (600 m) maximum as well as a deep-water (4000 m) minimum and a near-bottom (4800 m) maximum. Maxima correspond to the layers selected. The low-frequency currents in regions of other experiments listed above were shown to have similar features. Seasonal variability of kinetic energy of low-frequency currents in different layers is also discussed.

TURBULENT HEAT FLUXES AT THE BASE OF THE DIURNAL LAYER: A LAGRANGIAN ESTIMATION IN THE EQUATORIAL PACIFIC WARM POOL DURING TOGA/COARE EXPERIMENT

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The diurnal cycle in the heat budget of the upper equatorial ocean is studied using Lagrangian surface drifters equipped with temperature sensors between the surface and 20 m. They were deployed in the western equatorial Pacific during TOGA/COARE experiment (December 1992 - February 1993). The focus is on the estimation of turbulent heat fluxes at the base of the diurnal convective layer from budgets of heat content. We used near surface temperature data from drifters, solar short wave fluxes estimated from GMS satellite, wind speed from ECMWF analysis and TOGA/COARE bulk formulae (Fairall et al, 1996). We estimated night-to-day variations of turbulent heat fluxes at 20 m. The variations suggest that there is no net nighttime increase of turbulence in the warm pool region in opposition to what was earlier found from moored measurements in the central Pacific. However this result is dependent on wind conditions which have been very variable during the experiment. We also estimated an average diurnal cycle of the hourly turbulent fluxes at 20 m, and we analysed the deviations of turbulent fluxes from this average cycle. We interprate the results as a function of wind forcing and daily precipitations.

TRACER DISTRIBUTION AND VARIABILITY IN THE ARABIAN SEA DURING THE SUMMER MONSOON 1995

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The southwest monsoon forces a circulation with strong currents, gyres, and itensified exchange across the equator. The objectiv of this study is to analyse the ventilation of the Arabian Sea with the help of CFC (Chlorofluorocarbons) measurements obtained during three 'Meteor' cruises between April and September 1995. The mean CFC concentrations decrease exponentially from the surface to about 1000 m depth. Only the anomalies of the tracer field express the features of the circulation. The Somali Current transports fresh and freon-rich water from the southern hemisphere northwards. However, a part of this coastal current turns eastward and continues along 4°N . Only a minor fraction enters the northern Arabian Sea during the summer monsoon.

SENSITIVITY OF INDIAN OCEAN HEAT TRANSPORT TO CHANGES IN SURFACE AND LATERAL BOUNDARY CONDITIONS IN A BASINSCALE GCM

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A fully thermodynamic basinscale non-eddy resolving numerical model of the Indian Ocean region north of 30° S and west of 115° E is presented. The model features open boundary conditions in the Indo-Pacific throughflow region and the southern boundary of the model domain which allow the variation of a baroclinic Indonesian througflow and Aghulas current. Due to the coarse horizontal resolution of the model, sensitivity experiments with integration times in the order of decades are possible to investigate the role of the models boundary conditions in determining the annual mean heat transport in the Indian Ocean.
The structure and strenght of annual mean meridional heat transport appears to be most sensitive to changes in windforcing, throughflow strenght and southern boundary temperature distribution. While the Indo-Pacific throughflow only affects the strength and structure at and south of the throughflow region, windforcing and the southern boundary condition appear to alter the overall strenght and structure of the basinwide meridional heat transport and overturning. The windforcing can be identified as the main driving mechanism responsible for structure and amplitude of the seasonal cycle of Indian Ocean meridional overturning and heat transport that is much stronger than the annual mean.

ZONAL DISPLACEMENTS OF THE PACIFIC WARM POOL: A FUNDAMENTAL COMPONENT FOR ENSO

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The eastern edge of the western equatorial Pacific warm pool is subject to strong east-west displacements perfectly related with El Niño-Southern Oscillation (ENSO). These zonal displacements are essential in changing sea surface temperature in the central equatorial Pacific and therefore in driving the ENSO ocean-atmosphere coupled system. Within the equatorial wave-guide, the dominance of surface zonal advection in these displacements is demonstrated with four different current datasets and three ocean models. This demonstration is supported by the evidence of a convergence of water masses into the eastern edge of the warm pool, resulting in a salinity front. All these results lead us to propose a modification of the original delayed-action oscillator theory for the oscillatory nature of ENSO. In this new concept, zonal advection, current convergence and equatorial wave reflection on the western and eastern ocean boundaries are predominant. Simulations with a simple advective-reflective coupled model result in interannual oscillations in the 3-5 year range, depending on values of several parameters such as wind-forcing, Kelvin-wave phase speed and Rayleigh friction.

DEEP CIRCULATION IN THE SOMALI AND ARABIAN BASINS

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J. Fischer, F. Schott, and L. Stramma (Institut für Meereskunde an der Unversität Kiel, Düsternbrooker Weg 20, 24105 Kiel, Germany)
The deep layers of the Somali Basin are ventilated from the south and in turn ventilate the deep Arabian Basin through the Owen Fracture Zone in the Carlsberg Ridge. Hydrographic and current profiling measurements were made during the Southwest Monsoon of 1995 as part of the WOCE ISS2 program. These reveal a deep circulation pattern more complicated than expected from linear Stommel-Arons theory. The northern Somali Basin was dominated by an anticyclonic eddy carrying some 30 Sv in the depth range 1500 to 2500 m and a counter flowing narrow boundary current towards the west south of Sokotra Island. Measurements were also carried out at the eastern side of the Carlsberg Ridge in the Arabian Basin. It is estimated that the supply through the Owens Fracture Zone is about 3 Sv. The changes in the vertical hydrographic structure of the water columns in the two basin can be explained by frictional induced vertical mixing. The variability of the deep circulation in the northern Somali Basin will be discussed based on 18 months long current measurements with moored instrumentation retrieved in October 1996.

CIRCULATION OF THE WESTERN TROPICAL INDIAN OCEAN DURING THE SUMMER MONSOON OF 1995

M. Walter and F. Schott (Institut für Meereskunde, Düsternbrooker Weg 20, 24105 Kiel, FRG)

In 1995, several WOCE cruises have been carried out in the equatorial Indian Ocean by the German RV *Meteor* to study the response of the Somali current and the equatorial current system to the southwest monsoon. The data include CTD and oxygen measurements as well as current measurements from shipboard and lowered ADCP. Currents and water masses of the upper 500 m are studied in an area extending from the outer limit of the Somali EEZ to 58°E, and from 2°S to 8°N.

Transports have been calculated between certain density surfaces and are linked to the local water masses and their likely sources. In the fully developed southwest monsoon (Aug./Sep.) it was found for the isopycnal range between the bottom of the wind-mixed layer and the $\sigma_\theta = 27$ isopycnal at about 500 m depth that almost no water escaped from the "southern gyre" to the north but that most of it recirculated between 4°N and 2°S while a fraction escaped east across 58°E between the equator and 3°N.

OA5 Modelling large scale marine systems on High Performance Computers: a challenge for hydrodynamics, ecology and scientific computing

Convener: Berlamont, J.E.
Co-Convener: Vollebregt, E.A.

Sponsorship: E.U. Concerted action MMARIE (Modelling Marine Ecosystems using high performance computing) MAS2-CT94-0106

ADVANCED VERY HIGH HIGH RESOLUTION ECOLOGICAL MODELLING ON THE CRAY C90

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The European Regional Seas Ecosystem Model (ERSEM) has been coupled with the Princeton Ocean Model (POM) in a fully three dimensional implementation.
In order to carry out high resolution numerical simulations relative to the Adriatic Sea ecosystem dynamics (model grid size: variable from 3 to 12 km) it has been necessary to modify ERSEM to run on the CRAY C90. The final goal is to develop a version of the coupled model on a T3E parallel computer.
Results relative to the model performance, along with the simulated characteristics of the ecological state variables in the Adriatic Sea will be shown.

THE SOUTHAMPTON - EAST ANGLIA (SEA) MODEL: A GENERAL PURPOSE PARALLEL OCEAN MODEL

M.I. Beare (University of East Anglia, Norwich, England)

The Southampton - East Anglia (SEA) model is a general purpose Ocean General Circulation Model (OGCM) for ocean and climate modellers. The model has evolved from the GFDL Modular Ocean Model (MOM), but is designed to give good performance on high powered workstations, clusters of workstations and message passing massively parallel processor (MPP) systems, rather than vector processors. Parallelism is provided as a module option, with the technical intracacies being hidden from the user in high-level message passing routines. Using a two-dimensional geometric decomposition the model readily scales to any number of processors. From an initial implementation, bottlenecks that adversely affect the parallel efficiency of the model are highlighted. Solutions to these problems are then implemented and their validity on various platforms are discussed. The resulting code is reasonably efficient and can be readily used for all manner of research purposes on both scalar and parallel computers.

THE PARALLELISATION OF THE GHER 3D PRIMITIVE EQUATION MODEL, EXEMPLIFIED BY AN APPLICATION TO THE GENERAL CIRCULATION IN THE MEDITERRANEAN SEA

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The GHER 3D non-linear primitive equation including turbulent closure schemes and biological active components demands for important computer resources. As the numerical model implementation already has taken advantage of classical methods to increase performance (vectorisation, code optimisation, mode-splitting to increase time-steps etc.), the possibility of using parallel computers was investigated. Rather than to work at the code level, a more general approach was taken. A generalised domain decomposition technique was indeed designed not only to allow for a parallelisation of the model by distributing subdomains over the different processors, but also to allow the connection of models using different resolutions. In this way, nesting methods can be implemented in the same natural computational style as the already existing parallelised version. The method was tested on a real case application in the Mediterranean sea, where the model performance was increased by a factor 7 on the 8 processors of an IBM SP/2. This research was a contribution to the E.U. concerted action MMARIE (MAS2-CT94-0106)

MODELLING OF THE UPPER MIXED LAYER ECOSYSTEM IN THE BLACK SEA

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In the last years anthropogenic impact on the Black Sea has dramatically intensified, thus giving rise to the acute ecological problems. The present situation requires of the coupling on the one hand the advances of the fundamental oceanological disciplines, and on the other hand, the variety methods, technologies and scientific computing, that permit assess, at least roughly, ecological situations. The main components of this approach are in situ observations and remote sensing of the sea surface and methods of contemporary informatics (data bank, immetation models). As the first step to ward development ecological monitoring presented model of annual cycles of plankton dynamics and nitrogen cycling in the upper mixed layer. This is adapted model of Fasham and Ducklow (1990) to the Black Sea region. The model describes the transformation process between the blocks: Phytoplankton, Zooplankton, Bacteria, Nitrate, Ammonium, Detritus, Dissolved organic nitrogen. This choice of compartements permits a functional distinction between new and regenerated production. The model describes satisfactory annual variability of the elements and reproduces spring bloom. This model is able to evaluate the effect of natural and anthropogenic changes.

IMPROVING THE PERFORMANCE OF A COASTAL SEAS FLUID FLOW MODEL. NUMERICAL ASPECTS AND PARALLEL IMPLEMENTATION

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We describe the implementation of some techniques aimed at improving the computational performance of a coupled hydrodynamic and transport model in coastal seas. The computational impact of techniques to obtain a good matrix ordering, to exploit the matrix's sparsity pattern and to accelerate the iterative matrix system solution on the model performance is analized. Parallelization of the numerical model is achieved by grid partitioning and by a block variant of the standard ILU(0) preconditioner. The spectral bisection technique is used to partition the FEM mesh. Consequently, each submesh corresponds to a submatrix (a block) which can be treated independently. The main impact is that the number of the negleted coefficientes is minimized. Thus, the convergence degradation is not as severe as would be produced by a block ILU(0) version without partitioning. In order to accelerate the convergence of the BiCGSTAB solver even more, the Reverse Cuthill McKee Ordering is applied in each submesh locally. Therefore, a high ratio of scalability and a good parallel efficiency can be achieved. The parallel performance of the model is evaluated running a realistic model pro blem on the IBM SP2 machine (using MPI Protocol).

EXPERIENCES WITH A VERY HIGH RESOLUTION GLOBAL OCEAN MODEL ON A 512 PROCESSOR CRAY-T3D

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The UK's Ocean Circulation and Climate Advanced Modelling project (OCCAM) has successfully developed and run a high resolution, truly global, ocean general circulation model for use on MPP platforms. This $\frac{1}{4}^{\circ}$ (N-S and E-W) resolution model has been further optimised for use on a CRAY-T3D. In March 1996 additional processors were added to the National supercomputing resource maintained by the Edinburgh Parallel Computing Centre which increased the total number of processors available from 256 to 512. In response, the OCCAM project decided to implement a $\frac{1}{8}^{\circ}$ global model in an attempt to clarify the resolution dependency of some physical oceanographic features and to identify potential pitfalls with very high resolution models. Amongst the problems and solutions to be discussed are the best ways of getting over 3 GBytes of restart data distributed to, and collected from, the processors and methods for collecting intermediate "snapshots", with minimal interruption to the computational effort. A few results from both models will also be presented in order to illustrate the effects of the improved resolution.

IMPROVING THE ROBUSTNESS AND NUMERICAL EFFICIENCY OF A SOLVER FOR THE SHALLOW WATER EQUATIONS BY A PRECONDITIONED KRYLOV ITERATIVE METHOD

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Kian Tan (Delft Hydraulics, P.O. Box 177, 2600 MH Delft, The Netherlands)

In the TRISULA software, developed at Delft Hydraulics, time integration is done by a so-called AOI method (Alternating Operator Implicit method).
In the AOI method, the ordering of explicit and implicit steps at every time step leads to a system of equations for the water elevation. In TRISULA this system is solved by an ADI iteration process. When the time step is large, the ADI iteration does not converge very well. We describe how the method can be modified to obtain a robust solver, by using a Krylov iterative method with a (modified) ADI method as a preconditioner. This approach is also more efficient than the original solver, leading to lower execution times. The new technique will be illustrated by results obtained for the tide accurate simulation of the river Clyde.
We also describe how this method can be used and extended in case the preconditioner is based on domain decomposition. In this case, one can re-use certain vectors living in the Krylov subspace, which is constructed during the solution process. This makes the Krylov subspace method even more efficient and parallelisable.

PARALLEL IMPLEMENTATION OF A 3D BAROCLINIC HYDRODYNAMIC MODEL OF THE SOUTHERN NORTH SEA

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A fully non-linear 3D baroclinic hydrodynamical model of the southern North Sea with a horizontal finite difference grid resolution of 2.4 km (Proctor and James, 1996, Journal of Marine Systems, 8, 285-295) has been adapted to run on parallel processors such as the Cray T3D. The resolution of this model allows the simulation of baroclinic features at the scale of the internal Rossby radius to be resolved. Revision of the code to run on a parallel platform has provided the opportunity to run the model for a seasonal cycle (1989) during which both thermal and saline stratification occur. The model simulation is compared to observations collected during the UK North Sea Project with emphasis on measurements in stratified regions. Details of the parallel implementation will be provided together with an assessment of the models ability to resolve baroclinic features such as internal tides and coastal plumes, features important for future model developments incorporating biological and sedimentation processes.

PARALLEL SIMULATION OF EPISODIC POLLUTION EVENTS AT THE ZUMAIA COAST (N. SPAIN)

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In the vicinity of Zumaia (N. Spain) an aquaculture factory faces the problem of contamination events due to the discharge of the Urola river. This river drains a big industrial area and accidental spills of pollutants to the river course may result in deterioration of the water quality. The use of HPC Techniques is critical in this context, where quick reactions in front of spillage accidents are required. The factory can in such cases stop pumping water until water conditions improve. AZTI has surveyed the area in several occasions, collecting a large quantity of field data which have been used to feed a parallelized hydrodynamic and dispersion models developed jointly by LIM and AZTI. The local hydrodynamics is reproduced by means of two FE codes. The first one solves the steady-state version of the SWE by means of a penalty function approach, whereas the second one solves the transient SWE using a harmonic decomposition technique in time. The dispersion model solves the convection-diffusion equation by means of a FE Taylor -Galerkin scheme. Now, codes are supported by a Silicon Graphics Power Challenge shared memory parallel architechture provided with 8 superscalar processors. The model results have been validated thoroughly against field data and have proved to be accurate. As to parallel performances, speed up factors between 4.3 and 6.2 have been achieved.

THE ANGLIAN COASTAL MODELLING SYSTEM

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A two dimensional modelling system has been set up for the coastal waters of the English east coast, using the TELEMAC2D finite element code. In order to achieve reasonable run times and acceptable element sizes, it was necessary to set up a system with 8 hydrodynamic models. The detailed finer grid models, with a grid size down to approximately 250m, can be run over repeating tidal cycles, whilst the coarser grid models, with a minimum grid size of 500m, are run over entire spring neap cycles. The entire modelling system covers the southern part of the North sea, from Scarborough in the north to Bournemouth in the south, and consists of two regional models and 6 local models. Although the modelling system is developed to carry out investigations into the coastal water quality, the main element of the development was the development, calibration and validation of the hydrodynamic models. The calibration of the model is based on available water level information (synthesised as well as observed), and synthesised BODC currents for a number of stations. To support the model calibration, Anglian Water commissioned field studies, including seven Recording Current Meters covering the main coastal areas of interest. Calibration was carried out on data covering the first 15 days of July 1995, whilst validation was carried out for the second 15 days of July. In addition, drogue and dye experiments were carried out to support model validation and information from Admiralty Diamonds were also used. The performance of the model was judged objectively with the differences between the model simulations and observations converted into statistical information, using extensive sspreadsheets. The statistical presentation of the results take account of phase differences, accuracy of water levels, and currents, both speed as well as direction. This paper provides details of the methodology of model calibration and validation, and presents results of the calibration, including water levels, currents, drogues and dyes.

A SPECTRAL ELEMENT OCEAN MODEL ON THE CRAY T3D FOR THE MEDITERRANEAN SEA GENERAL CIRCULATION

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A new numerical model, SEOM(Spectral Element Ocean Model, Iskandarani et al.,1994), is considered to study the general circulation of the Mediterranean Sea. Spectral element methods combine the geometric flexibility of finite element techniques with the rapid convergence rate of spectral schemes. The current version solves the shallow water equations with a fifth (or sixth) order accuracy spectral scheme and about 50.000 nodes. The domain decomposition philosophy allows to exploit the power of the parallel machines due to the large inter-element computational complexity. The original MIMD master/slave version of SEOM, written in F90 and PVM, has been ported to the Cray T3D. When critical for performance, Cray specific high-performance one-sided communication routines (SHMEM) have been adopted to fully exploit the Cray T3D interprocessor network. Tests performed with highly unstructured and irregular grid, on up to 128 processors, show an almost linear scalability even with unoptimized domain decomposition techniques. Results from several years simulations on the Mediterranean Sea are shown for realistic bottom and coastline geometry. Both barotropic and first baroclinic modes are studied. The high resolution and accuracy of the model grid and numerical scheme allow us to study nonlinear equilibrium phenomena in the sub-basin scale gyres composing the Mediterranean Sea circulation.

A FULLY IMPLICIT 3D TRANSPORT-CHEMISTRY SOLVER COMBINED WITH DOMAIN DECOMPOSITION

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We are concerned with the numerical time integration of a transport-chemistry model. To avoid stability problems, we propose to use an *implicit* technique. We will consider a second-order Backward Differentiation formula and a third-order Radau method, which are both unconditionally stable.
The price to be paid in choosing an implicit method is that a large system of equations has to be solved in each time step. Due to the fact that we are dealing with 3 spatial dimensions and that chemical interaction of the species is involved as well, the coupling of this system requires a special solution technique.
We propose an iteration method, based on approximate factorization and diagonalization. An analysis of this iteration process leads to a condition on the time step in order to obtain convergence to the solution of the underlying implicit method. This time step restriction is, however, not very strict. It turns out that for rather large time steps convergence is obtained within a few iterations. Moreover, the iteration process has been designed in such a way that it allows for an efficient implementation on High Performance computers. We will show performance results obtained on parallel vector processor machines. Furthermore, we discuss a domain decomposition approach to further enhance the parallelism in the algorithm. This is also a very natural approach, since the present application often requires different spatial resolutions in different regions.

MODELLING COASTAL SEDIMENT TRANSPORT ON A PARALLEL COMPUTER

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The movement of the suspended sediments in estuaries and coastal environment cause many problems, e.g. siltation of navigation waterways, harbours and coastal environments. The sediment transport in tidal environment is rather complex. This is because of the complexity of the coastal hydrodynamics and the interactions of the sediments with the flow. Numerical simulation on tidal flow and sediment transport are popular tools for planning, design and management. Computations become extensive when the flow model and the sediment transport model are coupled. Especially when it is applied to the Belgian coast area the grid size becomes small (i.e. 75 m * 75 m) for resolving the complicated bathymetry. In order to improve the performance of the coupled model, the codes have been modified to run on a parallel computer (IBM/SP2). The modification includes transform from FORTRAN 77 code into FORTRAN 90 style for minimizing the memory usage. A communication library, MPI, is used for exchaging the information among the CPUs. The model results and model performance will be presented in the paper.

END USER'S REQUIREMENTS FOR COMPREHENSIVE HYDRODYNAMICAL AND ENVIRONMENTAL SIMULATIONS

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For many governments, like the Dutch Rijkswaterstaat, it is very important to have the disposal of a set of tools of high quality that are able to determine the hydrodynamical, the environmental and the socio-economical consequences of measures that have to be taken. The EU-MAST NOWESP programme has the entire European part of the Atlantic as a target area, including the North Sea. These high quality tools can also be used in large monitoring programmes, such as in EuroGOOS, the European Global Ocean Observing System.
Although scientists aim for a very fine modelling, in these areas a proper combination of mathematical and numerical approximations are the realistic approach. Only in the areas of interest for certain phenomenon a calculation should take place. For instance algea dispersion in coastal areas can be calculated by means of a 3D approach, whereas the watermovement in the open North Sea can be approached by a 2D model.
Even these approaches need a substantial amount of calculation. Preferably this is done by parallel computers. For end users but also for researchers, however, it is very important to have an optimal form of flexibility. Therefore the design of an Open Modelling Infrastructure (OMI) should be aimed at. This OMI gives the possibility of changing models, of domain and model decomposition and of parallel computation. It offers a maximum flexibility. Such an OMI only can be designed if end users feel the need and the developers join there efforts.

G6/OA6 Ocean modelling from altimetry and remote sensing

Convener: Knudsen, P.
Co-Convener: Le Traon, P.Y.

TOPEX-POSEIDON DATA ASSIMILATION IN AN OCEANIC GENERAL CIRCULATION MODEL OF THE TROPICAL ATLANTIC

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One year of TOPEX/Poséïdon altimeter sea level anomalies. eXpendable BathyThermograph temperature profiles, Sea Surface Salinities and Temperatures have been assimilated into a non-linear primitive equation model of the tropical Atlantic ocean during 1992-1993. The results are analyzed by comparison with reference data sets such as the CITHER 1 data set. The emphasis is on thermal, salinity and current structures in the upper layers of the tropical Atlantic. Analysis of transports has also been conducted, especially in the North Equatorial CounterCurrent area.

ASSIMILATION OF ALTIMETER DATA INTO A PRIMITIVE EQUATIONS MODEL USING A REDUCED ORDER KALMAN FILTER

J. Ballabrera-Poy and J. Verron (MEOM/LEGI, UMR CNRS 5519. BP 53X, 38041 Grenoble Cédex, France)

A Singular Evolutive Extended Kalman (SEEK) Filter is used to assimilate satellite altimeter data into a Primitive Equations model (the SPEM model, Haidvogel et *al.*, 1991). Experiments with simulated altimeter data are performed in a 4 layer adiabatic version of the model. Resolution is fine (20 km). Thus, the chosen physical parameters are typical of the intense mesoscale activity of the oceanic mid-latitude gires.
The SEEK filter (Pham et it al., 196) is a simplification of the classical Extended Kalman Filter, in order to avoid the problems due to the numerical cost of the assimilation algorithm. To do so, it is assumed that the estimation error covariance can be approximated by a singular low rank matrix. This is equivalent to selecting a finite number of directions (in the state space) in which the model trajectory will be corrected.
In a first step, we study a degraded form of the SEEK filter, in which the functional basis of reduced order is constant in time. In following experiments, we study the case for which this basis evolves in time, to best represent the fastest growing error components, which is one of the original features of the SEEK filter. The evolutive case is found to perform better than the static filter.

DYNAMICS OF NORTH ATLANTIC MODELS (DYNAMO): EDDY STATISTICS FROM MODELS AND TOPEX-POSEIDON

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The European MAST-II DYNAMO project aims at an improved simulation of the circulation in the North Atlantic Ocean by comparing three eddy-resolving models with different formulations for their vertical coordinate (using fixed horizontal levels, isopycnic layers, and topography following (sigma) coordinate). The models are forced by ECMWF monthly mean fluxes. Model configuration have been set up to be as nearly similar as possible for all models. Each model have completed a 15-year spin-up integration, followed by an additional 5-year intercomparison experiment. Solutions from the various models are compared with respect to their ability to reproduce important aspects of the circulation in the North Atlantic. We shall discuss the eddy activity of the various models, in particular the geographical and vertical distribution of eddy kinetic energy and sea surface height, and will compare it with altimetric estimates of similar quantities obtained from Topex/Poseidon. Already, we observed significant differences between models, and between models and altimetry, related to the different solutions they propose for the Gulf Stream system, the eastern basin dynamics, and to the different subgridscale parameterizations.

THE AGMASCO AIRBORNE GRAVITY AND AIRBORNE ALTIMETER SURVEY IN SKAGERRAK

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The MAST3 project AGMASCO organized in September 1996 an airborne gravity/ altimeter survey in Skagerrak employing the AWI Dornier 228 aircraft 'Polar4'. The airborne equipment include an upgraded LaCoste & Romberg air-sea gravity meter, a laser and a radar altimeter ,two geodetic GPS receivers and a data logging unit. The main goal was to establish an operational system to model the geoid and sea-surface topography by means of airborne gravimetry, airborne altimetry and carrier phase differential GPS. The system may prove to be an alternative remote sensing tool of ocean currents and a useful supplement to satellite altimetry in coastal areas where satellite data are lacking or of bad quality. Flight- and hydrographic ship-measurements (ADCP & CTD) were carried out simultaneously on an ERS-2 track crossing from Denmark to Norway, followed up by ground truth marine gravity measurements . Tidal and meteorological effects are modelled to correct altimeter data and in-situ ADCP measurements. The airborne system of the Skagerrak campaign will be presented together with gravimetric and oceanographic results

VARIABILITY IN THE SOUTH-EAST INDIAN OCEAN FROM T/P AND ERS1 COMBINATED DATA

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We seek to monitor the variability in the South-East Indian Ocean from altimetry by combining ERS1 and T/P data (1993). This region is important for climate studies, in relation to the interannual variations of the tropical oceans and atmosphere. The eastern Indian region is directly affected by the strong seasonal monsoons, which induce a seasonal ocean variability. Moreover, the Indonesian throughflow provides another ocean forcing between the Pacific and Indian Oceans. As a result, the dynamics of the southeast Indian ocean are unusual: the mesoscale variability off western Australia is very large for an eastern boundary and the cold equatorial upwelling doesn't exist.

T/P altimeter data provide a good means of accessing the long wavelength ocean variability. The combinated ERS1 and T/P data will be analysed and compared with mapped T/P data alone, in particular to better describe the mesoscale signal, on seasonal and interannual time-scales. This is important on this eastern boundary as the likely source of the westward propagating band of high energy between 20-35°S.

ASSIMILATION OF TIDE GAUGES AND XBT IN A TROPICAL OCEAN MODEL USING ADAPTIVE KALMAN FILTERING.

Isabelle Blanchet, SHOM/CMO

The Kalman filter (KF) is the optimal linear assimilation scheme when the first and second order statistics of the observational and system noise are correctly specified. Unfortunately, these statistics are usually not known. Optimality can be reached in principle by using an adaptive Kalman filter (AKF) which estimates both the state vector and the error statistics. The KF has to be implemented in a space of reduced dimension for computational savings.
The proposed adaptive algorithm has been tested using a twin experiment approach with simulated sea level data. The tropical ocean model is the Cane and Patton linear model. The AKF performance has been proven for different noises : white system and observational noise but also auto-correlated sytem or observational noise.
The AKF has been used to assimilate real tide gauge observations and dynamic height anomalies derived from XBT data. We present the results of the assimilation with this new AKF scheme compared to standard KF assimilation with a priori statistics.

DEVELOPMENT AND FIRST RESULTS OF AN AIRBORNE GEOID MAPPING SYSTEM FOR COASTAL OCEANOGRAPHY (AGMASCO)

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An airborne gravity and altimetry system has been developed and implemented in the research aircraft Polar-4 of the Alfred Wegener Institute. This installation is designed to operate in regions where satellites - due to their large footprint - are not able to resolve the local structures.
Differential GPS (DGPS) and an Inertial Navigation System are used to obtain a precise position and orientation of the aircraft. This high-accuracy navigation system provides the means for the determination of a local geoid model. Furthermore, in combination with altimetry measurements, the temporal surface topography can be determined. A few centimeters of surface elevation can be resolved. This implies, that sea surface disturbances due to oceanic currents can be detected.
A first regional survey has been carried out over the Skagerrak in September 1996. During the Skagerrak campaign, gravity and oceanographic measurements were performed simultaneously by the Norwegian research vessel HAKON MOSBY, our airborne survey and additionally satellite altimetry. The main objectives of this campaign were the determination of a precise geoid model and the detection of oceanic currents, by using this system in comparision to acoustic doppler current profiler measurements and to a circulation model. This model is run by the Norwegian Meteorological Institute. First results will be presented.

ALTIMETRIC ESTIMATES AND OCEANOGRAPHIC MODELS OF OCEAN DYNAMIC TOPOGRAPHY - COMPARISON OF A THREE YEARS TIME SERIES

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Satellite altimetry provides a repeated, fast, global and precise monitoring of the ocean surface. For longer wavelength the geoid, computed from improved Earth gravity models, can provide similar precision. This suggests to estimate the absolute dynamic topography from the differences sea surface minus geoid. On the other hand, high resolution results are available from hydrodynamic modelling. In the present paper we compare the results of both, the altimetric estimates and oceanographic modelling.
For this comparison a series of 107 ten day gridded mean sea surface topographies has been derived from the differences of Topex/Poseidon altimeter data and the geoid computed from the new high resolution EGM96 gravity field model. The series covers a period of three years. For the same grid and ten day sequence corresponding topographies were derived by resampling the surface elevation as provided by the POCM of Semtner & Chervin. The differences are analysed with respect to both, the geographical and temporal distribution. Results are illustrated and discussed.

REDUCED KALMAN FILTER APPLIED TO ALTIMETER DATA ASSIMILATION ON NORTH ATLANTIC

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We implement a singular evolutive extended (SEEK) kalman filter on a realistical model of north Atlantic, in order to assimilate altimeter mesurements of TOPEX/POSEIDON. The model, developped in Grenoble (SIMAN), is an high resolution (20 km) wind driven quasi-geostrophic model with bottom topography.
First, the reduction of a classical extended kalman filter consists in approximating the error covariance matrixes by low rank singular matrixes. This is realised by an EOF analysis of a reference experiment in order to initialise the filter with the covariance matrix represented by the r first EOFs and to reduce the initial error by projecting it on these EOFs. Then the subspace of correction has to be the best approximation as possible of the fastest growing error directions, in the phase space. According to the extended filter, the evolution of these directions is governed by the tangent linear model.
In our case, we try to improve the extended filter by using a dynamic, for the directions of correction which does not neglect the non linearities of our model: we represent the error evolution by a sample of $r+1$ points which follow the dynamic of the model.

THE AGORA PROJECT : DATA ASSIMILATION IN GLOBAL OCEAN MODELS FOR CLIMATE STUDIES

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AGORA is a project funded by the European Commission ENVIRONMENT programme. The main scientific partners are P. De Mey (GRGS, France), G. Evensen (NERSC, Norway), K. Haines (U. Edinburgh, UK), P.-Y. Le Traon (CLS, France), A. Navarra and N. Pinardi (CNR/IMGA, Italy), P. Rogel (CERFACS, France), and D. Webb (IOS, UK). The goals of the project are to perform global ocean data assimilation and prediction with altimeter, SST, and subsurface Levitus (1994) data in 1987-94; to test the quality of ECMWF reanalyses in forcing the global models; to provide initial conditions for seasonal forecasting studies in other projects; and to help intercompare innovative assimilation methods such as multivariate reduced-order optimal interpolation, the Derber and Rosati (1989) method, ensemble Kalman filtering, and the Lagrangian water displacement method. Medium-resolution, global primitive-equation models with various vertical coordinate systems have been set up. A special global altimetry dataset with TOPEX/POSEIDON, ERS-1, and ERS-2 data corrected for the long-wavelength residual errors is being produced and compared with the global integrations in forced and coupled mode. The comparison focusses on the characterisation of the seasonal cycle of the wind-forced variability and surface heat/salt storage (steric effects) in the surface topographic signature. On the other hand, twin experiments assimilating simulated data are under way, and give insight on differences of behaviour of data assimilation schemes in the tropics and in the mid-latitudes. Complementary studies regarding the statistical vertical multivariate structure of ocean variables in the tropics are carried out in the Pacific using TOGA/TAO, SURTROPAC, and model data. The talk will provide an overview of the most recent relevant results obtained by investigators, and serve as an introduction to talks on more specific aspects.

A HIGH RESOLUTION QUASI-GEOSTROPHIC MODEL OF THE NORTH EAST ATLANTIC ASSIMILATING ALTIMETRY - OCEANOGRAPHIC RESULTS AND COMPARISON TO SEMAPHORE DATA

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A high resolution (1/10th degree) quasi-geostrophic model of the North East Atlantic assimilating altimeter data from TOPEX POSEIDON and ERS satellites has been developped. This model coverage ranges from 24° N to 54° N and 35° W to the coast. There are ten levels on the vertical. This model was derived from the Blayo et al (1994) model. The assimilation scheme belongs to the Optimal Interpolation family and has been developped by P.
De Mey (pers. comm.). The inverse solution for this area by Paillet and Mercier (1996) is used at the open boundaries and for the assimilation of altimeter residuals. This model is aimed at being used in real-time with fast delivery altimeter data by the French Navy. Oceanographic results from this model are presented. The comparison with in-situ data collected during the SEMAPHORE (Aymard et al. 1996) in summer and fall 1993 are also shown.

AN IMPROVED MAPPING OF SEA LEVEL VARIABILITY USING T/P, ERS-1 and ERS-2 DATA COMBINATION.

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Since the launch of TOPEX/POSEIDON (T/P) in August 92, several altimetric satellites (T/P, ERS-1, ERS-2) are flying simultaneously. The situation is likely to recur in the future with missions like GEOSAT Follow On, ENVISAT, and JASON. While T/P unprecedented accuracy has provided a new picture of the ocean, its not possible to observe the full spectrum of the ocean movements with only one satellite; to resolve the mesoscale ocean circulation, another altimetric mission, at least, is then needed. The ERS satellites are thus an excellent complement of T/P sampling.
As part of the AGORA European project, CLS Space Oceanography Division is in charge of producing a combined and homogeneous data set of high quality altimetric data from 1992 onwards which will form a core period for special studies. Then, analyses of high resolution sea level maps obtained with T/P and ERS-1/2 separately and then with the combination of the three different data sets are performed to analyze the consistency of those data sets and the additional information provided by the merging of the data. Results of the merging of TOPEX/POSEIDON, ERS-1 and ERS-2 will be presented.

MESOSCALE VARIABILITY OF THE SEA SURFACE HEIGHT IN THE NORTH ATLANTIC AS MEASURED BY TOPEX/POSEIDON

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The circulation of the North Atlantic ocean plays an important role in the global heat and mass transport. The current system is strongly connected to variations in the sea surface height (SSH) which can be measured by satellite altimetry. In the present study we investigate the mesoscale signals in the region from 20° N to 65° N and from 0° to 82° E using SSH measurements made by the TOPEX/POSEIDON altimeter. Starting from along-track calculated SSH anomalies we compute the amplitudes and phases of the annual and semi-annual cycle and show that even on small spatial scales the amplitudes can differ by as much as 4 cm. The statistical quantities like RMS values and eddy kinetic energy clearly represent the structure of the North Atlantic current system and also variations of the SSH due to topographic features can be made out. In order to detect interannual trends we have performed these calculations for the entire period of the years 1993-95 as well as for annual time intervals. We can distinguish different areas where the SSH is rising or falling. The most pronounced signal during this period is a rise of about 5 cm of the SSH in the eastern part of the subtropical gyre.

ASSIMILATION OF ALTIMETER DATA IN A GLOBAL OCEAN MODEL

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A method for the assimilation of altimeter data into free surface primitive equation ocean models which conserves water-mass properties is presented. This method is implemented for the first time in a global ocean model (OCCAM). Results from a twin experiment are shown, where surface height fields from a previous model run have been assimilated, allowing the degree of convergence of the assimilation run towards this model 'truth' to be tested. New surface height fields were assimilated at 15 day intervals. Assimilation is seen to have produced significant improvement of all model variables, with global RMS temperature errors reduced by 50%, salinity errors by 40% and velocity errors by more than 60% after running for 135 days. The results are examined in specific geographical regions to assess the relative performance of the method in different flow regimes. Convergence is found to occur fastest in mid-latitudes, where the assumptions of stratified water, and no change in near-bed velocities form good approximations. Convergence occurs more slowly in tropical regions, where horizontal advection of tracers is important in defining the vertical structure, and in the Southern Ocean, where stratification is weaker and barotropic currents are stronger. Finally, early results of assimilation of TOPEX/POSEIDON sea surface height anomaly maps into the model are shown.

MESOSCALE VARIABILITY AND WIND FORCING

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The sea level anomaly of the North Atlantic has been described during the period from January 1993 to April 1995. The study is focused on the mesoscale regions that are linked to the major currents: the Gulf Stream, the No rth-Atlantic Current and the Azores Current. Their intensity and stretch change with time. The spacially averaged variability increases during the winter and su mmer. Which for ve 54°N, the wind effect is immediate. A physical interpretation is su ggested: the stretch, intensity and position of the strong mesoscale activity ar eas should be linked to a simple condition of a baroclinic long Rossby wave stop ped by a mean e baroclinic instability.

ALTIMETRIC ASSIMILATION INTO A MESO-SCALE PRIMITIVE EQUATION MODEL OF THE AZORES-MADEIRA REGION.

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P. De Mey (UMR5566-GRGS, Toulouse, France)
G. Caniaux (Meteo-France/CNRM, Toulouse, France)

We present altimetric assimilation results in a primitive equation model over a 1000km square area in the Azores-Madeira region. The model has a fine horizontal and vertical grid mesh, a special open-boundary treatment and uses the TKE vertical mixing formulation. Surface atmospheric forcing is provided by ECMWF-model data. The model starts from initial conditions obtained by vertical extrapolation from altimetry using multivariate isopycnal EOFs and geostrophy (Gavart and De Mey, 1996). The experiments consist in 6 months of simulation, from 1993/06/03 to 1993/12/01 overlapping the SEMAPHORE experiment period (Eymard et al., 1996). The assimilation method is based on optimal interpolation and two different ways of projecting the surface error are considered: the dynamical method of Cooper and Haines (1996) and the projection along the Azores Current EOF. In both cases, the assimilation considerably reduces the misfit between surface model forecasts and satellite observations, and the results compare well with independent in situ measurements from the cruise. We discuss the differences between the two methods and the role of atmospheric forcings.

ASSIMILATION OF SATELLITE ALTIMETRY WITH NORTH ATLANTIC CLIMATOLOGICAL HYDROGRAPHY

S. M. Grey and K. Haines (Department of Meteorology, University of Edinburgh Edinburgh, UK EH9 3JZ)

A method originally designed for assimilating satellite altimetry into general circulation models has now been applied to a climatological hydrography of the North Atlantic. The scheme assumes that sea surface height is not correlated with deep pressure variations and height anomalies are assimilated by a conservative vertical displacement of the thermocline.
Using Topex/Poseidon and ERS-1 altimetry, this method has been applied to climatological hydrographies of the North Atlantic from Levitus (1994) and Lozier *et al* (1995) to produce new hydrographic fields. Comparisons with *in situ* expendable bathythermograph data are reported. Improved currents can also be calculated geostrophically. It is hoped that, by this simple method, a better than climatological estimate of the sub-surface structure and currents can be attained based on satellite data.

EXPERIMENTAL STUDY OF THE INTERACTION BETWEEN AN EXTERNAL SOLITARY WAVE AND SHORT SURFACE MONOCHROMATIC WAVES

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Long internal waves generate signatures on SAR images of the sea surface by modulating the surface wave field. Up to now mainly internal wave characteristic length and phase velocities are extracted from these images. We suggest on an experimental basis that by analysing more precisely the surface wave field, information on the amplitude of the internal waves could also be retrieved.
We describe experiments performed in a 36 m long and 0.5 m wide wave flume to study solitary-short surface wave interaction. Two type of experiments are carried out : short monochromatic waves i n the 1 Hz to 3 Hz range are either propagating in the same direction (strong interaction) or in the opposite one (weak interaction) with respect to the solitary wave propagation. The experimental data consist of free surface elevation at one location versus time.
The surface wave part before the arrival of the solitary wave is phase shifted compared to the part after it. The dependancy of this phase shift with the solitary wave amplitude and the short wave frequency is examined. We show that strong interactions lead to much larger phase shifts than weak ones. The experimental data is also discussed by comparison with analytical models.
This study is supported by the E.C. under MAST III MORSE project : Mesoscale Ocean Radar Signature Experiments (N° MAS3-CT95-0027 DG12 ESCY).

REMOTE SENSING OF THE PHYSICAL AND BIOLOGICAL VARIABILITY OF THE EASTERN ALBORAN SEA

T. H. Guymer, J. T. Allen, P. Cipollini, G. Corsini, T. N. Forrester, H. M. Snaith, S. Fielding, J. N. Schwarz, D. A. Smeed, S. G. Alderson and P. G. Challenor

The Alboran Sea is composed of a number of gyres in which warm fresh water from the Atlantic overlies relatively cool, saline water formed within the Mediterranean. At the eastern end the Almeria-Oran Front, a dominant climatological feature, separates Atlantic Water from the Mediterranean water. At the front itself upwelling of transitional water takes place and biological activity is enhanced. A combined in situ and satellite measurement programme, OMEGA, to study the front took place during October to December 1996 involving two ships, an aircraft and the use of several satellites equipped with visible, IR and microwave sensors. The combined in situ and remotely sensed datasets have enabled a detailed description of the surface water types, the fronts that separate them, the bio-optical properties, and the associated changes around the time of the cruise. Shipborne measurements indicate that the surface signatures visible from remote sensed data are indicative of circulation to a depth of more than one hundred metres. The results of the merging and interpretation of such a comprehensive dataset are discussed in detail. They show the potential and capabilities of the combined satellite/in situ approach in rendering a picture of the relationship between the physics of the front and bio-optical variability at the mesoscale with an unprecedented degree of accuracy. Particular attention is given to the relationship of the observed biological variability to the 3-D circulation at the front and to assessing the influence of sub-surface patchiness in the interpretation of ocean colour data from satellites. Longer term monitoring of the dynamics of the Almeria-Oran Front should now be possible by the combination of the altimeter, SeaSoar and ADCP data to determine the cross-track surface geostrophic current over the lifetime of the ERS satellites.

ANNUAL VARIATION OF SEA SURFACE ELEVATIONS AND CURRENTS OVER THE SCOTIAN SHELF AND THE GRAND BANKS FROM THE TOPEX/POSEIDON ALTIMETRY

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The TOPEX/POSEIDON (T/P) altimeter data over the period 1992-96 have been analyzed to examine annual variability of the sea surface elevations and currents over the Scotian Shelf and the Grand Banks. A regional tidal model is employed to remove the oceanic tides from the altimetric sea surface elevations over these regions. To derive the annual cycle, harmonic analysis is applied to the time series of the sea surface elevations. The along-track sea surface slopes, which represent surface geostrophic currents, are also estimated along the T/P ascending and descending ground tracks. The altimetric results are compared with the solutions from a numerical model forced by baroclinicity, wind stress, and remote forcing. The comparison between the altimetric and modelled results indicates that the altimetric sea surface elevation variability is dominated by the baroclinic (and associated barotropic) component and supplemented by the wind-driven and remote-forced components. The altimetric elevations at Halifax and St. John's (interpolated from nearby T/P observations) agree favourably with the tide-gauge data, with an annual amplitude of about 5 cm high in late fall and low in late spring. The wintertime intensification of the shelf-break flows are suggested by the altimetric surface currents, consistent with the model solutions.

The Mediterranean Pathfinder SST dataset: from the statistical analysis to the boundary condition in Mediterranean OGCM

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The new Pathfinder SST dataset has been used to study the seasonal and interannual variability of the temperature field in the Mediterranean sea. The Pathfider data set consists of 12 hours maps at 9 km resolution for the entire world ocean. The data relative to the Mediterranean basin were extracted and two (day and night) objective maps per day were produced in order to fill the data gaps due to the cloud cover. These data were used to evaluate the time and space scales of the SST field and to follow the time evolution of some particularly interesting features like Iera -Petra anticyclone. EOF analysis was performed in order to evaluate the relative importance of the seasonal and interannual variability of the temperature field and mesoscale variability. The same data were used as surface boundary conditions for a derived Cox model of the Mediterranean sea. The model has a horizontal resolution of .25 degrees, 19 vertical levels and a buffer zone for the Atlantic region. We discuss some preliminary results from the comparison between the model runs using SST b.c. and those using climatological ones.

LARGE SCALE SEASONAL VARIATIONS OF ATLANTIC OCEAN BY COMBINING ALTIMETRIC AND HYDROGRAPHIC DATA IN AN INVERSE MODEL.

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The response of Atlantic ocean from seasonal atmospheric forcing is observed by combining, in an inverse model, 3 years of Topex-Poseidon GDR (T/P), 1993 to 1995, with a climatology built from NODC data. The first step has consisted to observe and to analyse seasonal large scale signals over the whole atlantic, as steric effect, and variation of surface circulation from sea level anomalies (SLA). Seasonal cycle is clearly seen in the tropics even though oceanic signal seems to be dominated by steric effect in mid-latitudes. For steric effect, a relatively good accordance is obtained between the estimation provided by ECMWF net heat flux and T/P estimation. The second step is dedicated to the combination of hydrographic and altimetric data. An inverse model is developped here to give seasonal results. Altimetry is used to constrain the seasonal surface topography, especialy at large scales, where the precision is better. Results of the inverse model provide various seasonals maps of each term contained in the heat balance equation, as advection, net heat flux (given by ECMWF field), and heat content. An attempt is made to quantify the spatial distribution of those terms.

GENERALIZED INVERSION OF SATELLITE CHLOROPHYLL DATA FOR THE PRIMARY PRODUCTION IN THE NORTH ATLANTIC USING A FOUR-COMPONENT ECOSYSTEM MODEL

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A technique of parameter estimation by solving the generalized inversion of an ecosystem model for the ocean upper mixed layer was applied to assess the primary production (PP) in the deep North Atlantic. The model used describes the budget of phytoplankton, zooplankton, detritus, and nitrate and was constrained by mean monthly CZCS chlorophyll data. Model inputs optimized in the study were phytoplankton maximum growth rate, initial slop of P-I curve, phytoplankton and zooplankton maximum specific mortality rates, maximum rate and half-saturation constant of zooplankton ingestion. Estimates of the annual primary production obtained are in agreement with those of S. Sathyendranath et al.(1995). Namely, the spatial distribution of PP demonstrate strong variations in the latitude with maximum values located in the vicinity of the Atlantic coast of the Great Britain. Assessments of phytoplankton maximum growth rate have also a noticeable decrease in the southward direction.

GLOBAL OCEAN DATA ASSIMILATION OF TEMPERATURE PROFILES: SENSITIVITY TO DATA COVERAGE

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The Derber and Rosati (1989) Optimal Interpolation scheme has been used to assimilate the latest World Ocean Atlas data set of Levitus (1994) for temperature vertical profiles. The data set is of unprecedented coverage in both hemispheres and we present a reanalysis of the assimilated temperature structure of the ocean after Rosati et al. (1995). The study period is 6 years starting from January 1987 ending december 1992 to partially overlap with Topex/Poseidon data wich will be used to validate the analyses produced only with temperature assimilation. The model is a global version of MOM at approximately 1x1 degrees of resolution and 1/3x1/3 degrees at the equator. Twice daily atmospheric analyses are used to force the model. Experiments are carried out with decreased amount of input data and the sensitivity of the analysis to the amount of data available is assessed. The tropical Pacific variability is discussed in detail with a comparison between simulations and assimilation runs.

OSCILLATION PATTERNS OF SEA SURFACE HEIGHT IN THE TROPICAL PACIFIC

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Climatic phenomena like El Niño are strongly influenced by the variability of the tropical Pacific ocean. Three years of TOPEX/POSEIDON altimeter sea surface height (SSH) data have been used to investigate the dominant oscillation modes in this area. The variabilities inherent in the observed SSH fields are studied using standard Fourier analysis as well as the method of empirical orthogonal functions (EOFs) and principal oscillation patterns (POPs). POPs are especially suitable for the detection of spatial patterns. Apart from the annual and semi-annual cycle, the predominant patterns of the SSH variability are given by the equatorial current system and by propagation of equatorial Kelvin and Rossby waves. Part of the variability of the SSH can also be ascribed to variation of the equatorial wind field. This has been found by comparison of the SSH oscillation patterns with oscillation patterns computed from the corresponding wind fields as provided by the European Centre for Medium-Range Weather Forecast (ECMWF). It is also shown that the altimetrically observed oscillation patterns of the SSH agree quite well with oscillation patterns calculated from SSH fields obtained from an ocean circulation model, the Hamburg Ocean Primitive Equation model (HOPE, Max-Planck-Institut für Meteorologie Hamburg).

STERIC SEA-LEVEL VARIATIONS IN A GLOBAL LOW-RESOLUTION OCEAN MODEL IN AN ASSIMILATION PERSPECTIVE

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The advent of Topex/Poseidon altimetry has evidenced sea-level variations to be dominated by steric variations at the larger scales. As most assimilation techniques have been designed for the mesoscale, where steric variations may be neglected, altimeter data assimilation into coarse resolution ocean models has to deal with this signal.

In this study, results from a 14-year forced global low-resolution run are used to compute straightforward steric sea level variations. The study discriminates steric contributions of upper and deep waters, and of haline and thermal variations. Both the mean seasonal signal and interannual variability are analysed. The upper ocean (200 m) heat content can explain more than 80% of the variance of the mean seasonal signal almost in all regions, except in the high latitudes where deep mixed layer develops during the winter. Salinity contribution is found small and its geographical distribution seems noisy, probably due to a damping term to Levitus climatology. Interannual variations are also dominated by thermal effects in the upper layers, but to a lesser extent, suggesting that deep changes in the density field are involved. After correcting for steric variations, the remaining sea level signal is weak and strongly correlated to the barotropic stream function signal.

Finally, a strategy for assimilating altimeter data into global models is presented in the framework of the AGORA project.

Relationship between Mediterranean Sea level anomalies from ERS and TOPEX/POSEIDON and subsurface sea structure from LIWEX and ERS-SYMPLEX experiments

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LIWEX and ERS-SYMPLEX data have been used to verify the performance of ERS and TOPEX/POSEIDON altimeters in the Mediterranean Sea. LIWEX experiment has been done during Winter-Spring 1995 in the Levantine basin to study the Levantine Intermediate Water formation and spreading. Although LIWEX experiment has been not designed for altimeters validation activity, the hydrographic data collected during this experiment firstly suggested the good correlation between dynamical height and Sea Level Anomalies in the Mediterranean Sea The ERS-SYMPLEX experiment has been carried out in the Sicily Channel during April-May 1996 to compare Sea Level Anomalies obtained form ERS-1/2 and TOPEX/POSEIDON altimeters with in situ data. During the cruise XBT and CTD casts have been densely done (about each 5 km) along all ERS-1/2 and TOPEX/POSEIDON tracks at the same time of each satellite pass. Measurements along satellite tracks have been repeated in order to relate differences between sea level measured by two altimeter passes and differences between dynamic heights derived from two corresponding hydrographic sections. Dynamic height have been calculated from CTD data and from XBT profiles, using T-S characteristics obtained by the CTD casts. The result of the comparison is very satisfactory and confirms the capability of the two altimeters to correctly detect both basin and mesoscale features of the Mediterranean circulation.

ON THE ASSIMILATION OF LARGE SCALE ALTIMETER DATA INTO PE MODELS

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We investigate different techniques of assimilating large scale altimeter data into the barotropic mode of a primitive equation ocean model. TOPEX/Poseidon data are first expanded in spherical harmonics of low degree and order. Subsequently they are assimilated into a version of the Hamburg Ocean Primitive Equation model (HOPE) which covers the the southern hemisphere.

Three different techniques are tested for their ability to constrain the barotropic circulation. The first one is nudging of the models sea surface height. The second method consists of a least squares fit to the models barotropic dynamics and the observational data involving pre-defined structurs. The third method uses a representer technique. A comparison of the methods is performed that takes into account their respective convergence properties and their inpact on the barotropic ocean circulation.

PRELIMINAR RESULTS FROM THE LARGE SCALE CIRCULATION IN SOUTH INDIAN OCEAN USING AN INVERSE MODEL

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A Large Scale Circulation Sheme of the South Indian Ocean between 20E and 120E is to be proposed, simulated by a nonlinear finite-difference inverse model with both hydrology and altimetry from Topex/Poseidon.

The inverse model grid has a 2-degree resolution in latitude and 5-degree in longitude. It is based on hydrology and is in geostrophic and hydrostatic balances. Constraints of inverse model are Ekman pumping derived from ERS-1 wind data, conservations of mass, heat and salt, and the planetary vorticity equation at the reference level. The dynamic height deduced from altimetry is added as a constraint of the model.

For the first experiment, only the deepest historical hydrological stations are considered. This data set is objectively interpolated on the model grid after an EOF decomposition on the vertical.

Reconstruction of the Word Ocean Large-Scale Circulation From the Sea Surface Height Data

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J. Schröter (Alfred-Wegener Institute for Polar and Marine Research, Am Handelshafen 12, 27570 Bremerhaven, Germany)

We propose and apply a method for reconstruction of the barotropic constituent of the global oceanic circulation from the large-scale dynamic sea surface topography. Mean large-scale currents are composed from low-frequency eigenmodes of the linear shallow water equations on geoid with the best fit to collected data in the least squares sense. Our major aim is development of a finite element hydrodynamic model and observation operator, spectral analysis of data with respect to the ability of its representation by the dynamical model, and solution of the inverse problem. Preliminary processing of TOPEX/POSEIDON altimeter data is done.

Decadal SSH variations in multi-satellite altimeter data and in the Hamburg LSG model

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Monthly sea surface height (SSH) variations from multi-satellite altimeter data (GEOSAT, ERS-1 and Topex/Poseidon) were combined to generate consistent SSH variations over the periods of these satellite missions. Corresponding SSH fields from 1980 to 1994 were derived from a global ocean circulation model - the Hamburg Large Scale Geostrophy (LSG) model. A comparison between these two data sets was first carried out regarding the phases and strengths of salient climatological events, e.g. El Niño and La Niña events during 1986-1988 and during 1992-1994. A variety of statistical analysis tools, e.g. empirical orthogonal functions, principal oscillation patterns, canonical correlations, were also used to describe and compare these two data sets.

Lately, multi-satellite altimetric SSH data were assimilated into the barotropic part of the LSG model using a least squares fit. Emphasis is placed on whether using altimeter data alone can yield satisfactory result or whether other data are necessary.

OA8 Intercomparison and validation of the ocean-atmosphere flux fields

Convener: Gulev, S.
Co-Conveners: Katsaros, K.; Taylor, P.K.

AIR-SEA FLUXES FROM OPERATIONAL ANALYSES FIELDS: INTERCOMPARISON BETWEEN ECMWF AND NMC ANALYSES OVER THE MEDITERRANEAN AREA.

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The ECMWF and NMC operational daily analyses of atmospheric parameters are used together with bulk formulas to compute heat and water fluxes in the Mediterranean. The basic fields used are winds, air temperatures and relative humidity (all at 1000 mbar level) and cloud cover (the compared fields are from ECMWF and COADS); the Sea Surface Temperatures used are from the Reynolds operational analyses. Water budgets (mainly evaporation minus precipitation) have been estimated using the ECMWF precipitation field; full basin and regional analyses were also performed, in order to highlight implications on water masses formation processes.
The intercomparison study period is January 1987 to December 1988 where relevant changes in atmospheric parameters indicated large summer warming of air temperatures and ocean temperatures correspondingly. Sensivity experiments are carried out in terms of frequency of the atmospheric parameters (6 hours, daily, weekly, monthly), selected height of parameters (surface, 1000 mbar) and different bulk formulations. The results of the GCM of the Mediterranean to these different atmospheric fluxes is shown and impact assessed.

RELATION BETWEEN GROWING SURFACE WAVE HEIGHTS IN NORTH ATLANTIC AND STORM FREQUENCY

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Observations of the last decades show a growth in mean significant wave height in the North Atlantic but no corresponding growth in the mean winds. With the wave model WAM, the hypothesis is tested whether an increased frequency of storms can explain such observations. To do so, a half yearly sequence of 6-hourly analysed wind fields is fed into WAM not only with the regular 6-hourly time increment but in two more simulations with reduced and enhanced time increments of 4 and 8 hours, respectively.
The model results are inconsistent with the contested hypothesis, which therefore is considered falsified. The faster succession of the wind fields in the "fast" run produces lower total significant wave heights instead of the hypothesized larger heights. This overall reduction can be traced back to lower energies of the non-fully developed sea states, which in turn may be related to the reduced duration of the forcing. A slight increase of the swell energy in the storm track due to a reduced duration of dissipation is overcompensated by the reduced wind sea energy. The reversed effect, an increase of the wind sea energy and a decrease of the swell energy in the storm track, is found in the "slow" run.

SIMULATED LONG-WAVE CLEAR-SKY IRRADIANCE OVER THE OCEAN: SPATIAL AND TEMPORAL VARIABILITY 1979-1993.

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Clear-sky long-wave irradiances calculated by a narrow-band radiation code applied to the ECMWF re-analysis (CLERA) are used to investigate the spatial and temporal variations in net surface long-wave radiative fluxes over the ocean. Monthly mean net long-wave irradiances from the atmosphere to the ocean surface, F_c (Wm^{-2}), are presented for the period 1979 to 1993. F_c is of order -90 Wm^{-2} between sea surface temperatures (SSTs) of 270 and 295 K. For SSTs greater than 295 K there is an increase in F_c to approximately -60 Wm^{-2} at 300 K. This feature is present throughout the year. The average $dF_c/dSST$ in the seasonal cycle (July-January) for 1985 is 5.3 $Wm^{-2}K^{-1}$. Cooling in the East Pacific from the El-Niño year of 1983 to 1984, for February, is associated with a 4.8 Wm^{-2} decrease in F_c per Kelvin decrease in SSTs. Decadal and daily variation in F_c is examined. Parameterization of this irradiance by adapting a simple expression developed by Prata (Quart. J. Roy. Met. Soc., 1996) gives values about 10% lower than those calculated by CLERA. The relationship between F_c and SST may be explained primarily by simple thermodynamics given its strong dependence on surface air temperatures and lower tropospheric moisture.

SATELLITE CLIMATOLOGIES OF RAINFALL AND SEA-STATE AROUND SOUTHERN AND WESTERN EUROPE.

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Historically it has been difficult to monitor rainfall over seas and oceans, because of the difficulty of locating rain-gauges on water surfaces, and to construct inventories of sea-state (surface wind speeds and wind stress) because observations of these parameters from ships are largely subjective, and confined to those locations or lanes in which shipping is present. With the advent of passive microwave images on Earth-orbiting satellites, it has become possible to evaluate and monitor these parameters much more objectively and uniformly through space and time than before. Research projects in the University of Bristol, funded by the European Commission and the UK Department of the Environment are generating Atlases of rainfall, surface winds (sea-state) and surface wind stress at a resolution of approximately 15km * 15km, commensurate with the resolution of "mesoscale" numerical prediction models now being developed, to cover the period during which the Nimbus-7 SMMR and the present DMSP Block 5-(SSM/I instruments have been operational, i.e. from 1978 through 1995. This paper presents the first results from these exercises, respectively covering the Mediterranean Sea, and the Eastern North Atlantic. Examples will be presented of the maps and statistics in the new *Atlases*, and some of the first interpretational information to emerge from them, of relevance to ocean-atmosphere fluxes.

WIND CLIMATOLOGY FROM ERS SCATTEROMETER

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The European Remote Sensing Satellites (ERS 1 and 2) contribute towards the improvement of the present knowledge of the global wind field. To date, the only long series of the surface wind vector (1991 - 1996) derived from satellite sensors are achieved from the ERS scatterometers. The nature of these surface winds allow evaluation of a new 1 spatial resolution global ocean surface wind parameters. Weekly and monthly wind fields are calculated. The probability distribution of wind over the world oceans is studied using the Weibull distribution. The seasonal and latitudinal variation are described. The accuracy of the resultant surface wind parameters is evaluated by comparison with buoys wind measurements. The new wind fields are compared to the meteorological analysis provided by ECMWF or to the published climatologies such as the Hellerman and Rosentein one. Annual and seasonal mean climatologies of wind stress, calculated from scatterometer data using the smith drag coefficient formulation, wind stress curl and sverdrup will be presented. The large and small scales features of the wind will be discussed.

CRITICAL TEMPERATURE RATIO IN LW RADIATION FORMULAE: A CASE STUDY FOR THE MEDITERRANEAN SEA

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Equations of the net longwave radiation ($IR \uparrow\downarrow$), the upwelling (counter) longwave radiation ($IR \downarrow$) and the effective emissivity of the atmosphere ($\epsilon_a\ (e, q, c, T_a)$) are refered in numerous different, sometimes equivalent forms. Being interested in $IR\uparrow\downarrow$, the upwelling longwave radiation ($IR\uparrow$), $IR\uparrow = \epsilon_s\, \sigma T_s^4$ has been added, when only $IR\downarrow$ was suggested. When only ϵ_a was suggested, $IR\uparrow\downarrow$ is calculated by $IR\uparrow\downarrow = IR\uparrow - \epsilon_a\, \sigma T_a^4$. Expressing $IR\uparrow\downarrow = \epsilon_s\, \sigma T_s^4 - \epsilon_a\, \sigma T_a^4$ implies a critical condition of the ratio T_s/T_a, when $IR\uparrow\downarrow \rightarrow 0$:

$$\left(\frac{T_s}{T_a}\right)^4 \rightarrow \left(\frac{T_s}{T_a}\right)^4_{\text{crit}} = \frac{\epsilon_a}{\epsilon_s} \qquad \text{for} \qquad \left(\frac{T_s}{T_a}\right)^4 \rightarrow 1 \Rightarrow \frac{\epsilon_a}{\epsilon_s} \rightarrow 1$$

i.e., the effective emissivity of the atmosphere tends to equal the emissivity of a black body. Negative values of $IR\uparrow\downarrow$ at the sea surface would imply a heat flux into the ocean due to $IR\uparrow\downarrow$, which is unphysical! Thus:

$$T_s < \sqrt[4]{\frac{\epsilon_a}{\epsilon_s}} T_a$$

Critical conditions are derived for longwave radiation formulae, most of which are discussed by Sellers (1972), Fung et al. (1984), Bigmani et al. (1995) and Prata (1996). We investigate the range of the ratio (T_s/T_a), within which these parametrizations are valid, on the basis of the ERA (6h forecast) data set (Re-Analysis, ECMWF, 1995) for the Mediterranean Sea.

INTERCOMPARISON OF VISUAL ESTIMATES OF THE OCEAN WAVES WITH MODEL WAVE HINDCAST, REMOTELY SENSED DATA AND IN-SITU MEASUREMENTS IN THE NORTH ATLANTIC.

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Three climatological ocean wave products are intercompared to each other and compared with in-situ measurements in the North Atlantic for the period 1979-1993. Visual wave estimates were updated from the COADS collection of individual measurements. GEOSAT, ERS-1, and TOPEX/POSEYDON altimeter wave signatures were combined and intercalibrated to produce a continuous climatology for the periods 1985-1989 and 1991-1995. Modelled wave fields were obtained by driving the WAM model with surface winds from the ERA project. Intercomparison of the three products for a 15-year period was done for (I) climatological means, (ii) seasonal cycle, and (iii) patterns of interannual variability. Although there is a qualitative similarity of spatial patterns, quantitative biases appear in the estimates of significant wave height. The strategy of calibration of different wave products and their comparison with in-situ measurements is discussed.

PERIODIC WAVE-BREAKING AND ITS EFFECT ON MOMENTUM-, HEAT- AND MASS TRANSFER AT THE SEA-ATMOSPHERE INTERFACE.

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A 1-D "once-through", i.e. directly coupled air-water model for the simulation of momentum-, heat- and mass transfer under conditions of periodic wave breaking is proposed. View from a fixed position, for most of the time between breaking events continuous surface passes, only for a fraction of that time disrupted surface passes. The latter time fraction is assumed to be given by the surface fraction of whitecaps. The model solves transport equations for momentum-, heat- and passive tracers "once-through" between an atmospheric reference position and the sea bottom. Turbulent transport is determined separately for air and water flow, solving transport equations for the turbulent kinetic energy and parametrizing the mixing length. The heart of the system is the interface submodel used as air-water coupling tool (Eifler, 1993). Applied bothside the interface , this model replaces the information provided by the turbulence equations in the respective first interface adjacent grid elements by the viscous layer resistance. During the passing of continuous surface the high viscous layer resistance generates high gradients of velocity, temperature and tracer concentration. Disruption of the sea surface destroys the viscous sublayers, i.e. during the passing of disrupted surface the high viscous layer resistance is replaced by a low resistance. The short time of low transfer resistance is however not long enough to decrease significantly the high gradients, which therefore, in combination with the low transfer resistance, produce high fluxes. Comparing the time integrated fluxes with experimental data shows that (air side governed) heat and momentum transfer as well as (water side governed) high Schmidt number gas transfer is well described.

DIFFERENT SURFACE FLUX DATA SETS TAKEN DURING THE SEMAPHORE EXPERIMENT AND THEIR IMPACT ON THE OCEAN MIXED LAYER

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L. EYMARD and H. GIORDANI

Several surface flux data sets were made during the SEMAPHORE experiment (autumn 1993; Azores region). Solar and infrared fluxes were derived from the geostationary METEOSAT satellite data set collected at the Centre de Météorologie Spatiale (Météo-France, Lannion) on a very fine mesh. Model output, including ECMWF analyses and reanalyses of the French forecast model ARPEGE, provided atmospheric parameters and surface fluxes. Atmospheric parameters were also collected on board of the SUROIT, and turbulent fluxes were estimated using the inertial dissipation method to tune the bulk parametrisations. These different data sets are compared and validated with the in-situ measurements. The turbulent fluxes have been computed using the Dupuis et al. (1996) bulk formulae and have been compared with those from the ECMWF and ARPEGE models. These different fluxes set are used to force an oceanic mesoscale model in order to estimate the flux incertainties on the oceanic mixed layer.

FRESHWATER TRANSPORT IN THE NORTH ATLANTIC OCEAN: INTERCOMPARISON OF BALANCE AND DIRECT ESTIMATES

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The meridional transport of freshwater in the ocean (FWT) was determined with traditional formulation (Stommel, 1980) as a divergence of water flux in a control volume with different salinities on its boundaries. FWT may be obtained by "the direct method" using oceanographic data at any latitudinal section. An alternative technique is "the water balance method" containing an integration of evaporation, precipitation and runoff volumes. Seasonal budget of freshwater includes changes of freshwater storage in the upper ocean layer. To obtain seasonal FWT the characteristics of the North Atlantic evaporation and precipitation were taken from NCEP/ NCAR Reanalysis-96, runoff - from (World water balance..., 1974). Monthly freshwater storage was evaluated from the salinity data NODC-94. Freshwater budgets of the North Polar ocean and marginal seas were also estimated. The results revealed significant FWT seasonal variations of order 2 Sv, the most part of uncertainties was explained by the noise of salinity data. Direct measurements with annual mean wind data at 24N, 36N and 48N allowed to estimate FWT of order 0.3-0.5 Sv southward in 1981-1993 and 0.0-0.4 Sv in the late 1950s. These values coincided well with monthly mean freshwater flux derived from water balance.

CLIMATE OF THE SOUTHWEST ATLANTIC ACCORDING TO ECMWF RE-ANALYSES OVER THE PERIOD 1979-1990

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The ECMWF re-analyses (ERA) project provide a data set generated by a modern, consistent data assimilation system. The southwest Atlantic is a region where air sea interactions are strong and where meteorological in situ data are quite sparse. We examine here key parameters in air sea interactions as provided by the ERA over the southwest Atlantic (net heat flux, wind speed, wind stress curl and evaporation minus precipitation). They are compared to da Silva's Climatology, former ECMWF analyses and in situ or satellite data when available. Fundamental parameters such as clouds or SST entering in fluxes computation are also examined. Clouds in the reanalysis are much more realistic than in the former ECMWF analyses. Variability of each parameter at different time scales is analysed. The variability is particularly large in region with a net heat loss from the ocean to the atmosphere (the Brazil Current overshoot), especially in winter. It is true for all parameters. The variability is dominated by an annual cycle and small periods in the net heat flux, and by period less than 14 days in wind and evaporation minus precipitation. The interannual variability over the Brazil Current overshoot is important for each parameter.

THE EFFECTS OF THERMAL WIND CIRCULATION NEAR OCEAN FRONTS

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A relationship between the sea surface temperature gradient and the wind component in its direction is investigated. The inferred cause is uneven heating of the air from below. The climatological analysis is confined to the Newfoundland Basin and Kuroshio areas and is based on the COADS and SECTIONS data sets. The results are compared with the Hsu (1984) model and some results from FASINEX (Friehe and Williams, 1988). The findings are demonstrated to differ for Voluntary Observing Ships and Ocean Research Vessels (ORV). In the case of ORV the magnitude of the thermal wind component is closer to what can be inferred from simple theory. Possible reasons for this are discussed. The adjustment of air temperature gradient to the underlying surface temperature gradient is considered. The patterns of such an adjustment are different in the two regions which is accounted for by (1) different spatial orientation of the main storm tracks and (2) different distance between the hydrological front and the coast line. These patterns also change with the wind direction. Seasonal variability of the thermal wind components is assessed. In the Newfoundland Basin, the thermal wind circulation is simulated better than in the Kuroshio area. The explanation of this is given.

Can state-of-the-art observationally-based surface flux fields help us identify systematic errors in climate models?

P. Gleckler

There now exist a diverse variety of observationally-based estimates of ocean surface momentum and heat fluxes, but the uncertainties associated these products are in general not well quantified. An important motivation for efforts to improve these data sets is to provide validation data of climate model simulations. In this study it will be demonstrated that, despite the large uncertainties in the observationally-based products, they are proving useful in the identification of systematic errors in climate model simulations. The most serious types of surface flux errors typical in state-of-the-art AGCMs will be classified, and an attempt will be made to identify their causes. The priorities of modelers in need of improved observational products will also be discussed.

SEA STATE DEPENDENCY OF DUAL FREQUENCY ALTIMETER MEASUREMENTS

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The retrieval from microwave backscatter of geophysical parameters such as wind speed or friction velocity, is strongly dependent on the electromagnetic model employed and the physical processes accounted for. In the particular case of altimeter, Chapron et al.[1994] showed how diffraction of high frequency electromagnetic waves by small scale roughness improves interpretation of the Normalized Radar Cross Section. They were able to reproduce a well defined transition in Ku band sensitivity observed near u*=23cm/s, presumably associated with the onset of air flow separation and wave breaking. Thus, the inclusion of diffraction makes the measured mean square slope much more dependent on the state of the atmospheric boundary layer above the waves; this property was recently used to directly obtain friction velocity from Dual frequency altimeter data (Elfouhaily,1996). Another step is necessary to retrieve the wind speed at 10 meters height; it requires using Significant Wave Height (SWH) measurements, and a wave age dependent drag relation, but the SWH approach implies a finite range of validity. It excludes, for example, some swell contaminated or fetch limited wind seas, where exceptional roughness to wave age relationships are invoked. We use a dataset derived from colocated Topex altimeter and NDBC buoy measurements of wave spectra and wind. With some regional studies (such as in the Gulf of Lion), we can further analyze and distinguish swell or fetch effects on Nadir backscatter.

THE POTENTIALITIES OF SATELLITE MICROWAVE RADIOMETRIC METHODS OF REMOTE SENSING OF THE OCEAN/ATMOSPHERE INTERFACE

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The main problem in the remote sensing heat exchange processes on the ocean/atmosphere interface is the influence of the characteristics of the upper atmosphere on the signals measured by satellite radiometric sensors. Our previous studies solve this problem by taking into account the intercommunication between the natural radiation of the ocean/atmosphere system and the temperature/humidity characteristics of the near surface air. This link is more obvious for the seasonal and intraannual variations of the monthly mean values. Therefore, the atmosphere heat/humidity characteristics have been first evaluated for the large-scale ocean-atmosphere heat interaction. In the cooperation with the colleagues from the P.P. Shirshov Institute of Oceanology, RAS considered the next tasks: a) the correlation between simulated natural microwave radiation and boundary heat fluxes over active zones of the North Atlantic; b) adaptation of the bulk-aerodynamic formulae to a more convinient form for the use of satellite radiometric data; c) relationships between boundary layer heat fluxes and the microwave radiometric measurements from the DMSP satellites (the data have been obtained in the NASA MSFC DAAC). Our long-term interests include the understanding of the validity of satellite-derived radiometric data in order to study air/sea heat interaction not only with the emphasis on its seasonal and climatic but also on synoptic scales. Some preliminary results of this study are presented in the report which are based on the data of meteorological and aerological measurements carried out during "Atlantex-90" experiment in the Newfoundland active zone of the North Atlantic.

COMPARISON OF NCEP/NCAR REANALYSIS WINDS WITH IN-SITU DATA IN THE NORTH ATLANTIC.

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NCEP/NCAR Reanalysis winds for the period 1980-1994 are compared to instrumental measurements collected in the North-West Atlantic during field activity under the SECTION programme, OWS measurements, and to NCDC buoys data. Instrumental data set from the SECTION programme was collected at ships with known anemometer heights. Only a part of these data was transmitted via the GTS, thus they provide good opportunity for independent intercomparison. Additionally synoptic resolution data from OWS C, L, and M, and from NCDC buys wind records were used for comparison. Thus, different regions of the North Atlantic mid-latitudes were studied in a view of the reliability of NCEP/NCAR Reanalysis winds. Biases in reanalysed wind products are different from those seen in the COADS data.

ASSIMILATION OF SURFACE-WAVE SPECTRAL PARAMETERS FOR AIR-SEA FLUX MODELING

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A surface-wave spectral partitioning approach with automated wind sea isolation and swell-tracking capabilities was developed to extract and assimilate wave system statistics from directional wave spectra. Input spectra are first segmented based on peak locations and spectral slope at surrounding grid points. The recombination of selected segments, based on peak separation and spectral-spread criteria, results in spectral partitions that represent individual wave systems. Wind seas are identified using a wave-age criterion with an equilibrium-range threshold test. Swell systems are automatically tracked over time by their evolution in frequency and direction space. Automated storm-source identification is achieved using swell evolution statistics and linear gravity wave theory. Wave spectral parameters obtained from the partitioning approach significantly improve the standard power-law model for whitecap formation on the ocean surface. The method has significant potential for the assimilation and use of surface-wave spectral parameters for global-scale flux models.

VALIDATION OF PRECIPITATION FIELDS AT SEA

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Global fields of precipitation now become available from numerical weather forecasts and satellite remote sensing. To validate these techniques a ship rain gage had been developed for use at moving ship. In order to calibrate the ship rain gage in natural rain, an optical disdrometer has been designed and built that allows to determine drop size distributions between 0.35 mm and 6 mm with a resolution of 0.05 mm. This instrument thus is also suitable to provide a Z/R relation to calibrate radar for areal estimates of rainfall. The technique to validate precipitation from numerical weather forecast models against ship measurements of rain has successfully demonstrated for the Baltic Sea.
For use with historical data bases like COADS only precipitaion frequencies or estimates by the Tucker method based on visual estimates of precipitation intensities is available. In order to improve this method, we have recalibrated the Tucker method based on an extensive set of rain measurements on stationary light vessels in the German Bight, where 6 and 12 hourly instrumented rain measurements were available together with weather observations. Recalibrated in this way the method will allow to calculate fields of precipitation amount for the world oceans that could be used to verify climate models. Examples for the North Sea and Baltic Sea will be shown.

THE VIERS-1 SCATTEROMETER MODEL

P.A.E.M.Janssen, H.Walbrink, C.J.Calkoen, D.van Halsema, W.A.Oost and P.Snoeij (to be presented by W.A.Oost, Royal Netherlands Meteorological Institute, de Bilt, the Netherlands)

The VIERS-1 (Verification and Interpretation ERS-1) project has resulted in a new algorithm for the interpretation of the wind scatterometer, based on a physical model of air/sea/radar interaction in which the radar backscatter is calculated from wind and wave conditions. The model is inverted to obtain the wind from the radar backscatter. For operational purposes the model was coupled to the WAM wave model, which provides first- guess wave information. The performance of VIERS-1 has been compared with that of CMOD4, the algorithm presently in operational use, which is mainly based on statistical fitting. Using operational data it has been found that the results of VIERS-1 were comparable with those of CMOD4, with VIERS-1 outperforming CMOD4 slightly at both high and low wind speeds, but with CMOD4 providing a somewhat closer fit in backscatter space.

The SOC Global Air-Sea Heat Flux and Wind Stress Climatology

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Global climatological air - sea heat and momentum flux fields will be presented. The fields have been derived from in situ reports in the COADS 1a dataset, covering the period 1980-93, which have been blended with additional metadata from the WMO47 list of ships in order to allow corrections to be made for biases arising from observational procedure. The accuracy of the fields will be discussed in the context of results from local comparisons with buoy measurements and their ability to close the global heat budget. Results from an intercomparison with the Subduction Experiment array of buoys which were deployed in the sub-tropical North Atlantic over a two year period will be presented which show that in well sampled regions the climatological mean net heat flux is in agreement with the buoy value to within 5 W/m2. A comparison of the climatologically implied ocean heat transport in the Atlantic and Pacific with independent hydrographic estimates will be made. It will be shown that agreement between the climatology and hydrography can be obtained in the Atlantic given a 15% reduction to the calculated shortwave flux in the tropics and the possibility that this reduction can be attributed to the neglect of aerosol loading in the original calculations will be discussed.

IMPACT OF DIFFERENTIAL THERMAL FORCING ON THE ATMOSPHERIC BOUNDARY LAYER IN THE SEMAPHORE EXPERIMENT

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G. CANIAUX

A one dimensional coupled model has been developed to simulate both the oceanic and the atmospheric boundary layer. A parameterization of the warm microphysics has been implemented in the atmospheric model to generate cloud layers and this parameterization is coupled with a radiation scheme. A bulk parameterization is used to calculate the turbulent fluxes at the air-sea interface from atmospheric and oceanic parameters calculated by the model. Data from the SEMAPHORE experiment are used to evaluate the response of the atmospheric boundary layer on each side of the Azores thermal front, where the sea surface temperature differ by more than 1C over a distance of 100km. The simulations indicate significant differences in the simulated cloudiness on each side of the front. The surface fluxes are analyzed to understand the differences between the two simulations.

INVESTIGATIONS OF IONIC COMPOSION OF WATER ON THE UNEQUILIBRIUM BOUNDARY SEA - ATMOSPHERE

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The thin surface layer of the sea differs greatly in its properties from the bulk water. It is clear that this layer determines all the details of heat and mass transfer between sea and atmosphere, and therefor affects climate of the planet. In that layer most remarkable are steep temperature gradients exceeding 1 K/mm, the surface being colder than the underlying layers of water. The hypothesis that this gradient is responsible for almost all physical-chemical differences between the cold layer and bulk water was tested in field experiment at the Black Sea 1995-1996. The crosscorrelation functions for the temperature gradient and fractionation of inorganic ions (sodium, potassium, calcium, sulphate and chloride) were calculated and some of them proved to be substantial. Investigations showed also that functioning of biosystems such as neuston must be taken into account for explanation of diurnal changes of pH in the thin surface layer. The experiment in situ proved that the temperature gradient is very sensitive to the solution-s surface contamination, especially with surfactants and oil. Thus the research into the relationship between physical, chemical and biological processes on the sea-atmosphere boundary and human influences on them are of great importance now.

INTERCOMPARISON BETWEEN SURFACE HEAT FLUXES AND HEAT CONTENT CHANGES OF THE WESTERN MEDITERRANEAN

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Surface heat fluxes from various sources (May, COADS, ECMWF) are compared to seasonal heat content changes of the Western Mediterranean. For the COADS data a number of different bulk-parametriziations are evaluated. A reasonable agreement between heat content changes and surface heat fluxes calculated from COADS data can be achieved.
The seasonal heat content changes of the Western Mediterranean have been derived from climatological temperature data. Historical temperature measurements collected from various sources have therefore been compiled to a climatology. Combined with estimations of the heat transports through the straits of Gibraltar and Sicily the heat content changes can be compared with seasonal surface heat fluxes.

REGISTERED TEMPERATURE ANOMALIES IN THE OCEAN CAUSED BY THE BOTTOM EARTHQUAKE NONLINEAR STREAMS

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The local zones of the ocean surface low-temperature anomalies were discovered above the bottom quake epicenters near Solomon Islands. The magnitude of the variation from the average value was -3 degrees Celcius. The anomaly horizontal size was as great as 500 km. The life time of the anomaly has achieved 24 hours. The physical model was presented that explains the phenomenon by using of the approach of nonlinear acoustic. The assessment of the anomalies contribution in the heat balance of the system "ocean-atmossphere" was made.

ENERGY AND MOMENTUM FLUXES BETWEEN OCEAN AND ATMOSPHERE FOR THE ATLANTIC OCEAN FROM COADS

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Ocean-atmosphere fluxes for the period 1940 to 1979 are derived from individual COADS observations. Using bulk-parameterizations, the wind speed is essential for turbulent fluxes of energy and momentum. But even today the majority of marine wind observations consists of Beaufort estimates. Special efforts are necessary to convert estimates into metrical wind speeds, with particular attention to error variances and natural variability. Because previous scales do not meet these requirements, we derived a new Beaufort equivalent scale by a calibration with wind speed measurements from Ocean Weather Stations (OWSs). Additionally, wind observations were compared to simultaneous pressure differences between the reporting ships. Assuming a constant relationship between wind speed and pressure gradient throughout the years, a time dependent equivalent scale is obtained. An additional correction is applied for wind stress evaluations, because observation errors, even if random, would cause a systematic bias. Furthermore, COADS temperature measurements of air, sea surface and dew point were compared to the available OWSs in the Atlantic and Pacific, in order to remove systematical errors of the turbulent heat fluxes. Together with the radiative fluxes the net heat exchange is computed. Its integration provides a northward heat transport of 0.47 PW across 30°S. The evaluated wind stress causes a Sverdrup tranport of about 25 Sv across 30°N. Both results are in good agreement with oceanographic estimates.

AIR-SEA HEAT FLUXES DERIVED FROM SUB-SURFACE DATA IN THE NORTHEAST ATLANTIC.

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The seasonal heat budget of the upper 500 m of the North Atlantic between 33 and 63°N and 55 and 5°W was investigated using the Levitus and Boyer (1994) climatology and the Isemer and Hasse (1987) wind stress fields. Near the Polar Front geostrophic advection, Ekman advection and eddy diffusion were as important in the seasonal heat budget as the air-sea heat fluxes but showed only a small seasonal cycle. In contrast, along a line extending between the Azores and the British Isles the contribution of advection and diffusion combined was consistently less than 20±20 W m^{-2} compared with the climatological air-sea heat fluxes which vary seasonally between -140 and 110 W m^{-2}. Therefore, along this line it is errors in the observed heat content change that limit the accuracy to which air-sea heat fluxes can be inferred from the heat budget, and the larger errors in estimates of the advection and diffusion can be avoided. The collection of more sub-surface data here would help in deriving independent air-sea heat fluxes for use in testing the various bulk formulae flux fields. Using the existing Levitus data the seasonal air-sea heat fluxes were inferred from the heat budget along this line with an error of 30 W m^{-2}. The inferred fluxes agreed with the Isemer and Hasse (1987) fluxes in spring and summer, but predicted 50 W m^{-2} less ocean heat loss over the autumn and winter.

HEAT AND WATER BUDGETS IN THE ADRIATIC SEA: SEASONAL AND INTERANNUAL VARIABILITY

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Adriatic sea surface heat and water budgets for the period 1991-1994 have been computed from the ECMWF high frequency operational analyses.
The obtained climatological values are in good agreement with previous estimates of the Adriatic Sea heat and water budgets. However, this analysis has revealed important interannual variations in the magnitude and the sign of the heat budget. In particular the heat budget for the year 1994 is positive, while multiyear averages for the Adriatic Sea give a negative heat budget.
Implications for the Adriatic Sea thermohaline circulation are discussed.

IMPACT OF WIND WAVES AND SEA SPRAY ON AIR-SEA EXCHANGE OF HEAT AND MOISTURE

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Waves extract a considerable part of the surface stress. While breaking they eject spray into the atmosphere. Spray evaporates and influences a balance of heat and moisture above waves. A 1D model of the marine surface boundary layer (MBL) accounts directly for the impact of waves on the momentum flux and impact of the sea spray on fluxes of heat and moisture.
This model is viewed as a higher order parameterization of the MBL compared to the bulk parameterization. The model is based on the balance equations of momentum, the turbulent kinetic energy and the dissipation rate, heat and moisture. The exchange coefficients for heat, moisture, and momentum are computed from the wind speed and the sea state. The consistency of the dynamical part of the model is checked against measurements of the drag coefficient. The consistency of the thermodynamical part is checked against measurements of the sensible heat flux for moderate winds. The impact of spray is then assessed for strong winds. Several spray generation functions are tested.

CLOUD STATISTICS ANALYZED USING SATELLITE DATA

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The main objective of this work is to obtain maps of cloud properties of interest in the knowledge of the earth-atmosphere radiation budged using satellite images. Cloudy pixels have been extracted using a cloud detection program which uses VIS/IR images for day and IR alone for retrieving cloudy pixels in night time. The analyzed zone corresponds to a window of 512*512 pixels centered at the Iberian Peninsula. The data set analyzed covers 1994 and 1995. Results obtained include monthly averaged cloud parameters measured at different times of the day. Parameters obtained are cloud amount, minimum temperature, maximum reflectance and others. In particular, the dayly time evolution of low level clouds is analyzed in some detail in order to evaluate the effect of low clouds on the surface radiation budged, specially on shortwave radiation. As in the Cloud Atlas results, results are harmonically fitted. The phase and amplitude of the first harmonic are used as descriptors of the low level cloud fraction.

QUASI-PERIODIC OSCILLATIONS IN LATENT AND SENSIBLE HEAT FLUXES.

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Quasi-periodic oscillations(QPO), present on sea level sensible and latent heat fluxes, in the North Atlantic sector extending from 70W to 10E and from 20 to 60 N are identified and correlated with QPO detected in other meteorological variables, such as mean sea level pressure.
The basic data set, comprises twice daily sensible and latent heat fluxes, obtained from ECMWF over a 1.85x1.85 latitude-longitude grid, covering the five-year period between January first 1985 and December thirty one 1989.
The method used to identify the QPO is the multichannel singular spectrum analysis (MSSA) which gives a rather complete space-time and spectral picture of the oscillating phenomena in a wide range of time and space scales.
Oscillations with periods between two days and three months are isolated. Results and their relationship, with synoptic-scale disturbances, moving over a warm ocean are presented and discussed.

PARAMETERIZATION OF AIR-SEA FLUXES IN GLOBAL CIRCULATION MODEL FOR LIGHT WIND CONDITIONS

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A study on air-sea fluxes parameterization for GCM under light wind conditions is presented. The difficulty is to take into account subgrid convective motions of the atmospheric boundary layer to compute surface fluxes at large scale because convective activity generates most of the horizontal wind variability. At small scale, the fluxes are related to wind velocity, so at large scale, the efficient wind is the mean wind velocity $U_m = \overline{\|\vec{v}\|}$, but it is different from the velocity of the mean wind $U = \|\vec{\overline{v}}\|$ computed at each grid point of GCM. There are two different ways to get U_m from U, depending on the type of convective motions encountered. In case of fair weather convection (undisturbed conditions), intensity of convective motions can be related to the free convection velocity w_* by means of free convection coefficient β (Godfrey and Beljaars, 1991): $U_m^2 = U^2 + (\beta w_*)^2$. For deep convection events (disturbed conditions) $U_m^2 = U^2 + U_g^2$ where the gustiness velocity U_g can be deduced from dowdraft intensity or rain rate (Jabouille et al., 1996). Here only the case of undisturbed conditions is detailed. The flux intercomparison day of TOGA-COARE is studied using Large-Eddy Simulation. Comparison of different ways (obsevational and numerical) to estimate free convection parameter β shows that it can not be estimated precisely in using temporal variances, the only parameter available from surface observations. LES provides $\beta = 0.6$ which is close to the value of 0.7 ± 0.1 found by Shumann (1988). Estimation of β using wind temporal variances gives a value of 0.8 from LES and from ship obsevations during this day of TOGA-COARE too.

Comparison of Longwave Net Radiation at Sea Surface between Ship Measurement and Estimation from Satellite Observation

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Longwave net radiation over oceans is an important component of the surface energy budget, which determines the interaction between ocean and atmosphere. Infrared radiometers on satellites have been used in the past to derive the longwave net radiation at the surface. We apply a neural network to calculate the longwave net radiation over oceanic area from microwave radiometers such as the Special Sensor Microwave/Imager (SSM/I). The neural network applied in this study is able to account largely for the non-linearity between the longwave net radiation and the satellite measured brightness temperatures. In contrast to the regression method the error is reduced from 17 W m-2 to 5 W m-2 according to our model results. The algorithm can be applied for instantaneous measurements over oceanic regions with the area extend of satellite passive microwave observations (usually 30 to 60 km in diameter). Measurements from passive microwave radiometers provide a good way to calculate the longwave net radiation because most clouds are semi-transparent but still detectable in the microwave range. Undetectable high clouds which have almost no effect on the surface longwave net radiation cause no problems for our approach, but will deteriorate results based on infrared methods. Moreover, the microwave signal over ocean surfaces contains directly the information about downwelling radiances due to the high microwave reflectivity of the sea surface. The method presented here is successfully tested with model results. Validations of the method is also performed with ship measurements. For clear-sky cases a good agreement with an error of less than 5 W m-2 for the longwave net radiation between calculations and pyrgeometer measurements is obtained. For cloudy cases the error is about 20 W m-2, but the comparison is problematic due to the spatial inhomogenities of clouds and the low and also different resolutions of the SSM/I data. Global monthly mean values of the longwave net radiation are computed and compared to the other sources. Differences are observed among the climatological values from Lindau and Hasse (1996) and from Isemer and Hasse (1985) and our results.

USE OF SALINITY TO IMPROVE OCEAN MODELING

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Coupled model El Nino/Southern Oscillation (ENSO) forecasts are dependent on the initial state of the ocean model. Examination of errors in our ocean model indicate that the upper ocean salinity needs to be improved. To do this a method was developed to produce monthly sea surface salinity (SSS) analyses in the tropical Pacific from 1979-95 using ship track data from Orstrom (Noumea, New Caledonia). Because, these data do not provide a complete field, the surface forcing fields of SSS, evaporation minus precipitation (E-P), were used to fill in the SSS data. This was done by computing empirical orthogonal functions (EOFs) from the E-P anomalies. The ocean model was relaxed to the SSS fields at the surface, and the dynamics of the model carried this correction to deeper levels. The ocean model fields were compared to observations to determine if the model salinity and model sea level agreed better with independent data. The SSS analysis and the ocean model and data intercomparisons will be discussed.

Comparison of ECMWF reanalysis wind fields with ERS-1 scatterometer winds

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Uncertainties in the surface air/sea fluxes limit the interpretation of results obtained by the oceanic circulation models. Very few direct measurements of these fluxes are available and ocean modellers currently use fluxes computed by the atmospheric numerical models. At the European Centre for Medium Range Weather Forecasts 13 years of reanalysis with a consistent set of atmospheric and surface observations and with one fixed numerical model is being completed and will be widely used to force oceanic models. The period covered is 1980 through 1993.However these data must be validated in order to meaningfully interpret the ocean model results. The Department of Oceanography from Space at IFREMER has produced a uniformly processed weekly gridded wind field and derived wind stress field based on the European Remote Sensing Satellite 1, ERS-1, scatterometer data. These data cover the period August 1991 to close to the present time. These winds are validated by comparison with various buoy networks. Of special interest is the tropical Pacific ocean because the TAO array provides a unique data source for validation tests. Satellite and buoy winds show good agreement and ERS-1 winds were further evaluated by using the three- dimensional ocean model OPA7 developed at LODYC. This ocean model has been forced over the tropical Pacific ocean by the ERS derived wind stress fields and the ocean model results are compared with buoys measurements. These latter results assess the usefulness of the satellite observations and concurrent ocean model runs forced by atmospheric models are under investigation for comparison purpose. The work presented here is mainly to compare the satellite wind and wind stress fields to those of the ECMWF reanalysis for the period 1991-1993. This will provide a complementary analysis with what is done by groups using the Coordinated Ocean Atmosphere Data Set, COADS, particularly in the North Atlantic Ocean where the ERS-1 coverage is relatively poor.

DIFFERENCES BETWEEN ERS1, ECMWF,STATE OF THE ART METEOROLOGICAL MEASUREMENTS AND VOLUNTARY OBSERVING SHIPS IN THE AGULHAS CURRENT

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The oceanic region south of Africa and the Agulhas Current has been shown to play a key role in the control of Southern Africa weather and climate. A research program to investigate ocean-atmosphere interactions in these key areas has been instituted. The first step was to measure the air-sea exchange in those area. The results of a dedicated cruise at the Subtropical Convergence (STC) are presented here. An intense, meso-scale warm eddy detached from the Agulhas current was investigated. This warm water in the eddy created a strong sea surface temperature contrast and inhomogeneity in the overlying atmosphere. A comparison between ERS1 and ECMWF wind speed, supported by the meteorological measurements show that ECMWF model does not seem to take into account oceanographic heterogeneity such as a warm eddy, the Agulhas Current and STC. This provided ample motivation for a shipboard, automatic air-sea interaction monitoring system that could go aboard the three Sea Fisheries research vessels, S.A. Agulhas, Africana and Algoa. On the S.A. Agulhas meteorological measurements are made by the South African Weather Bureau according to World Meteorological Organization guideline. We compare those measurements to our automatic weather station.

Comprehensive Validation of Satellite-Derived Surface Energy Fluxes and Rainfall in the Tropical Pacific

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Satellite-derived fluxes of sensible and latent heat as well as surface rain rates are compared to in situ measurements gained in the tropical western Pacific during four months of the TOGA-COARE campaign. The validation study is completed with data from the RV/Vickers cruise along the equator and through the eastern subtropical Pacific during the CEPEX field phase. Energy fluxes and surface rain rates are determined using measurements of the SSM/I (Special Sensor Microwave/Imager) and the AVHRR (Advanced Very High Resolution Radiometer). Surface rain rates directly retrieved from SSM/I measurements are compared to doppler radar measurements carried out on the RV/Vickers. An adjusted bulk parameterization scheme is used to compute sensible and latent heat fluxes from both the in situ data and the satellite-derived bulk parameters. Time series of the relevant bulk parameters and the surface energy fluxes are presented for different stations within the COARE region. Time series analysis shows that the local variability of the surface energy fluxes is represented within the error bounds of the retrieval algorithms. Additionally, TOGA-COARE region averaged fluxes are computed from the irregular distributed in situ measurements and compared to the averaged satellite-derived fluxes.

LOW FREQUENCY VARIABILITY IN THE UPPER TROPICAL ATLANTIC OCEAN

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We focus on the low-frequency variability of the vertical displacement of the 20°C isotherm (Z20) in the tropical Atlantic. Opportunities to construct Z20 long-term series from observations (XBT probes) are exceedingly limited. Our alternative was to look at the Z20 long-term series simulated by an OGCM, after testing primarily the accuracy of the model results vs. the observed data fields, where and when that was possible. The OGCM OPA7 developed at LODYC is forced on a « tropical Atlantic zoom » during the 1985-1994 years by the outputs from the AGCM ARPEGE developed by Météo-France.
A series of tests was provided by analysis of Z20 anomalies along the XBT ship-track Dakar-Capetown. For both observed and simulated data sets, most of the abnormal events initiate at the equator, then they seem to move slowly poleward. This appears to corroborate the influence of the (equatorial and coastal) Kelvin and Rossby waves in establishing the interannual variability in the upper ocean.
A challenge was to examine if any low-frequency relationship exists between each hemisphere, according to a similar diagnostical exercise that was done for the SST Servain's dipole index. The simulated « Z20 dipole index » can remarkably be compared with both the observed and simulated « SST dipole ». Because the effects of the thermohaline circulation in the entire Atlantic Ocean are not accounted for by the used OGCM, that could indicate that the low-frequency variability in the tropical Atlantic subsurface could be mainly explained by local air-sea interactions.

PILOT RESEARCH MOORED ARRAY IN THE TROPICAL ATLANTIC

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Pilot Research Moored Array in the Tropical Atlantic (PIRATA) is a collaborative multinational effort (Brazil, France, USA) to install and maintain an array of 14 moored ATLAS buoys during the years 1997-2000 in the tropical Atlantic. Moorings will be spanned along the equator and two meridional lines (at 35°W and 10°W). This specific configuration has been chosen to provide coverage of strong wind forcing in the western basin and significant seasonal-to-interannual variability in SST in the central and eastern basin. The meridional arrays cover the regions of high SST variability associated with the SST dipole mode. The variables measured will be surface winds, SST, sea surface conductivity (salinity), air temperature, relative humidity, incoming short-wave radiation, rainfall, 10 depths subsurface temperature, 3 depths subsurface conductivity and pressure. The measurements will be transmitted via satellite in real-time, and will be available to all interested users in the research or operational communities. The ATLAS mooring systems will be built by NOAA/PMEL at Seattle, and the logistic support in terms of shiptime for developing and maintaining the PIRATA moored array will be mainly the responsability of Brazil and France. The main role of PIRATA is to complete the existing and future status of the observing system in the region, and to give adjustable and truth elements to future model experiments. Many scientific interactions will take place between PIRATA and other climatic programs. PIRATA has the potential to establish the foundation for a longer term monitoring network that will address more completely these important scientific problems under auspices of CLIVAR, GOOS and GCOS.

OCEAN THERMOHALINE SURFACE FORCING FROM ECMWF ANALYSES

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A major objective of global ocean circulation modeling is to simulate the quasi-equilibrium state of the ocean under climatological atmospheric forcing. The internal consistency of the forcing is an important criterion to select atmospheric data to drive model simulations of the ocean circulation. Numerical Weather Prediction centres represent a great opportunity to oceanography since they provide fields of surface variables on a global and regular coverage, which are dynamically consistent through model dynamics and parameterizations. At ECMWF, the analysis system is optimised for a medium range (10 days) forecast. Little attention is given to the impact that changes in the analysis system have over seasonal to interannual periods. Continuous modifications performed to the analysis/forecast system aim at improving the forecast but limit the possible use of the analysis for climatological studies. ECMWF has just performed a re-analysis of meteorological observations through the years 1979 to 1993 with a recent version of the model. However, to evaluate the accuracy of the ocean surface fluxes produced by the re-analysis will require some knowledge of the variability of the fluxes estimated by atmospheric models in the last decade. This is the purpose of the present paper which performs a long term evaluation of ECMWF surface fluxes for the period 1986 to 1995. Practical objectives are to determine the impact of the changes in the operational system on the monthly and annual average of surface fluxes and precipitations, and to assess the accuracy of the analyses in term of forcing ocean general circulation models.

Wind, stress and temperature in the Antarctic sea ice region from model and observations

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The surface fields of geostrophic wind velocity, atmospheric stress and surface air temperature have been determined for the Antarctic sea ice zone from operational analyses of the European Centre for Medium Range Weather Forecast (ECMWF) and with the aid of in-situ measurements provided by the WCRP-International Programme of Antarctic Buoys (IPAB). The geostrophic wind values of both data sets agree fairly well for monthly averages when the buoy measurements are assimilated into the ECMWF-model.

Relatively large discrepancies are found for individual days due to inaccurate locations of atmospheric pressure systems and fronts in the model analyses. In coastal regions obviously the coarse resolution of the orography leads to systematic errors of the model wind velocities.

The still remaining differences between the model and buoy derived geostrophic wind velocities result in uncertainties of the surface stress which are larger than the effects of possible variations of the hydrodynamic surface roughness or of the static stability in the atmospheric surface layer.

Similar to the geostrophic wind values the monthly means of the near surface (2 m) atmospheric temperatures derived from the model analyses and measured at the drifting buoys are in good agreement. But the observed temperature variance is considerably higher than the variance of the model values. If the model surface temperatures are reanalyzed with the aid of a surface energy balance scheme which accounts for the ISCCP cloud data and SSM/I ice concentration values the model variance is increased but stays still distinctly below the one of the measurements.

Since the surface turbulent heat flux results from the correlation of the air-ice (or water) temperature difference and the wind speed the discrepancies between the model and observed values are expectedly larger than those of single quantities.

STATISTICAL PROPERTIES OF GLOBAL SIGNIFICANT WAVE HEIGHTS AND THEIR USE FOR VALIDATION

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Numerous global data sets of significant wave height (H_s) are nowadays available from spaceborne altimeter measurements and from wave models. Due to data assimilation in models some sources lost their independency giving cross-va lidation only relative relevance. We performed a statistical approach for data validation. The statistical properties of H_s determined from measurements of the altimeters aboard Seasat (1978), Geosat (1988), ERS-1 (1993, 1994), and TOPEX (1993, 1994) and from the wave model WAM (1988, 1993) are compared with those from in situ measurements of the Ocean Weather Station M in the North Atlantic. The statistical properties from linear regression, principal component analysis, first four moments of linear order statistics and empirical distribution functions are then used to evaluate the quality of the data. In this way, deficiencies of H_s from the Seasat and the ERS-1 altimeter (1993) can be uncovered. Simple functions are unlikely to correct these deficiencies properly. Furthermore, the changes induced through different wave and atmospheric model versions or the continuous development of sensor algorithms are seen to be large compared to the interannual and decadal variability. The creation of unbiased climatologies from different H_s measurements is difficult and need to be complemented by homogeneous geophysical modelling approaches.

HEAT BALANCE ESTIMATES USING ATMOSPHERIC ANALYSIS DATA AND OCEANIC RESPONSE TO ATMOSPHERIC FORCING. A CASE STUDY FOR THE BLACK SEA.

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The behavior of fine resolution numerical ocean models forced by high frequency atmospheric data differs substantially from the one, known from coarse resolution studies. This includes different pathways of heat flux between atmosphere and ocean, which can affect the formation of water masses. The Modular Ocean Model (MOM) based on Bryan-Semtner-Cox circulation model is applied in the present study to the Black Sea and is used as a tool to produce data, which are then analyzed. The heat balance, based on classical bulk formulas is estimated using the U. S. National Meteorological Center atmospheric analysis data and different types of sea surface temperature data. The contribution of the short-period variability to the heat flux components is evaluated. It is shown that the use of monthly averaged atmospheric data produces substantial inconsistencies in the heat flux estimates due to inaccurate calculation of the nonlinear terms in the bulk formulas. Error estimates for experiments using independent sea surface temperature data are analyzed. We found that the formation of cold water in the Black Sea depends strongly on the variability in the thermochaline and mechanical forcing. It is shown that the ocean-atmosphere heat flux at eddy scales is comparable to the heat flux due to the high frequency variability. The corresponding ocean response is estimated in the paper.

ANALYSIS OF IRE-SEA INTERACTION PARAMETERS THE OCEAN USING AN OPTONORMAL WAVELET TRANSFORM

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The wavelet transform techniques was used to provide a signal which preserves coherent structures. A wavelet analysis can supply information of both the location (time) and the scale of fluctuations. This method is applied to the fluctuations of the components of wind velocity, temperature and humidity above the ocean. The data of marine experiments are used. The shapes of both the wavelet spectra and the Fourier spectra of this parameters are similar to each other. The contribution of meso scale structures in the heat and momentum fluxes are considered.

AEROSOL FLUXES AND THEIR GRADIENTS IN THE MARINE BOUNDARY LAYER OVER THE COASTAL ZONE

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Based on the size distribution function and concentrations of aerosol particles which were determined in the coastal zones of the southern Baltic Sea by means of the lidar method the aerosol fluxes and their gradients in the marine boundary layer were derived. Since 1992 the measurements have been carried out under various weather conditions and in various seasons of the year taking into consideration such factors as wind direction, duration and velocity as well as different types of sea bottoms. The lidar measurements were calibrated by simultaneous measurements with six stage cascade impactors and a particle measurement system. It was determined that aerosol fluxes and their gradients in the measuring area varied seasonally and they were relatively high when the winds blew from the shore as well as in fall and winter. Additionally, the dependence of aerosol fluxes on sea bottom slope and shape as well as sea roughness were confirmed.

VALIDATION OF ERA WINDS FROM WAVE HINDCASTS USING WAM

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The ERA project (= ECMWF ReAnalysis) resulted in a homogenous dataset describing the atmosphere from 1979 to 1993. To validate (part of) these date against independent observations we use the ERA surface winds to drive the WAM wave model. The modelled significant wave heights H_S are compared with observations to asses the quality of the forcing winds. It appears that the modelled wave heights are systematically lower than the observed ones. It is argued that this discrepancy cannot be explained by model deficiencies, but must result from the ERA winds being too low, which probably comes from the ERA resolution of T106 being insufficient to capture high wind speeds. The hindcast data also form a 15-year climatology of global waves which is searched for trends. The largest trends in H_S occur in the North Atlantic with up to 12 cm/y in January and south of Africa with up to 8 cm/y in July. They are, however, only marginally significant and exhibit a large month-to-month variability, so that on a seasonal basis the trends are significant only in small parts of the ocean. Concluding, the wave climate has not changed significantly during the ERA period.

COADS RELEASE 2 DATA AND METADATA ENHANCEMENTS PLANNED TOWARDS IMPROVEMENTS OF FLUX FIELDS

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The Comprehensive Ocean-Atmosphere Data Set (COADS) has been updated through a cooperative U.S. project since 1981, including vital international contributions. Quality controlled ship records now covering 1854-1993, have been supplemented in recent years by drifting and moored buoy data. Monthly statistics of fluxes and basic marine variables are calculated for each year using observed data falling within 2° latitude x 2° longitude boxes (1°x1° summaries are also available for 1960-93). Enhancements in data and metadata planned by the year 2000 as part of COADS Release 2 (~1820-1997) will concentrate on the basic observational records. In addition to new data sources, which will augment flux estimates through expanded coverage, planned enhancements include: a) usage of selected metadata from WMO Pub. No. 47 (ship instrumentation history) to improve the observational records back to about 1973; b) improvements in the reliability of the wind speed ("estimated/measured") indicator; and c) bias adjustments of wind speed Beaufort estimates and anemometer measurements.

OPERATIONAL THERMAL SKIN EFFECT PARAMETERIZATION

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The skin layer at the ocean-atmosphere boundary represents the "bottleneck" for all transport processes. Due to the viscose character of this thin layer (order 1 mm at the oceanic side) the temperature gradients become quite sharp in the presence of heat flux. This difference between the skin and the bulk sea surface temperature is of the order of some tenths of Kelvin. It must be properly parameterized for estimating the sub-surface temperatures from skin measurements, f.e. with infrared radiometers.

Thus, we derive analytic expressions for the temperature difference as well as for the transfer coefficient. We compare critically a number of model assumptions applying them to regimes of free and forced convection including the limit of breaking waves. The models are mainly based on the surface renewal ansatz. A recommendation for an operational parameterization using the wind velocity and heat flux is derived, the regional applicability is discussed.

OA9/ST21 Biogenic air-sea fluxes and processes in coastal and marginal seas

Convener: Buat-Menard, P.
Co-Convener: Owens, N.J.

THE GIRONDE ESTUARY : A MAJOR HETEROTROPHIC SYSTEM

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The Gironde Estuary is a typical macro-tidal estuary of the European Atlantic zone, with pronounced influence of terrigenous organic inputs and long residence time of both water (3 months) and particles (18-24 months).The sedimentological budget of organic matter (evaluation of input-settling-output) reveals the disappearance of a huge amount of particulate organic carbon inside the estuary, whereas dissolved organic fraction behaves conservatively. The main part of the organic material which disappears in the estuary is from terrigenous origin: on the one hand, the estuarine primary production remains low whatever the season (light limitation effects due to high suspended matter content); on the other hand, the labile fraction of the fluvial organic matter is quite important. Mineralization processes within the estuary then appear predominant: settling and resuspension cycling of particulate material plays an important role in these mechanisms. The recent studies of CO2 distribution and related atmospheric exchange confirm the importance of mineralization processes. Interesting correlations between CO2 emissions and organic loads are expected when comparing the data obtained in different estuaries (Scheldt, Gironde and Rhine estuaries).

NATURAL AND ANTHROPOGENIC VOLATILE METAL AND METALLOID COMPOUNDS IN ESTUARINE ENVIRONMENTS

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The distribution of dissolved and atmospheric volatile compounds of trace metals and metalloids has been investigated along the Gironde, Scheldt and Rhine estuaries. An analytical method, involving cryogenic trapping, GC and ICP/MS allowed us to perform simultaneous determinations on several trace elements. Water and atmospheric samples were collected during 6 cruises on the Gironde, Scheldt and Rhine estuaries along with hydrological parameters. Significant results were obtained for Hg, Pb, Se and Sn. Volatile Hg was mainly found as elemental Hg in both phases. Potential natural and anthropogenic sources of Hg^{o} in estuarine environments are then suggested. Volatile Pb was mainly detected in the atmosphere and under the molecular forms used in gasoline enrichment. Gaseous deposition of Pb in estuarine waters may also be established. Volatile selenium compounds in estuarine waters were found to be related to biological methylation processes and a large fraction of dissolved Se evades to the atmosphere. Volatile tin compounds have been discovered probably originating from both biomethylation processes and TBT release from antifouling paintings. Interactions in estuarine environments between anthropogenic inputs and biological activity lead to the formation of volatile metals and metalloids compounds. Gas phase exchanges of these elements seems to be significantly important to re-examine their coastal cycling.

DISTRIBUTION OF METHANE AND NITROUS OXIDE IN THE WESTERN ODER ESTUARY (SOUTHERN BALTIC SEA)

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Methane (CH_4) and nitrous oxide (N_2O) were measured as part of the German *GOAP* project at several sampling stations located in the various sub-basins of the estuarine system of the Oder river (southern Baltic Sea). Four cruises took place between 1994 and 1996. We determined atmospheric and dissolved N_2O and CH_4 by using a GC-ECD/FID system interfaced to a seawater-air equilibrator. The CH_4 saturation values showed a great seasonal and spatial variability and ranged from 300 to 16,000 %. Nitrous oxide saturations were near equilibrium with the atmosphere. Enhanced N_2O concentrations where only observed near discharges of nitrogen-rich waters. Air-sea flux estimates indicate that the investigated coastal waters play a significant role in the biogeochemical cycling of CH_4 and N_2O in the Baltic Sea ecosystem.

IN-SITU MEASUREMENT OF NITROUS OXIDE USING AN ELECTROCHEMICAL SENSOR

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A functional sensor designed for the in-situ determination of nitrous oxide is described. The technique uses dual polarisation to quantitatively reduce oxygen and nitrous oxide (N2O). The resulting measured current is proportional to ambient concentrations of the respective species. A specialised data acquisition programme has been developed to supply the required pulse trains with integrated signal capture. The inherent flexibility within this control system allows the utilisation of several types of electrode e.g. a micro-electrode for sediment work or a planar electrode for water column work. This system has recently been tested on a North Sea cruise.

NITROUS OXIDE IN ESTUARIES AND COASTAL WATERS

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Three years worth of concentration data distributions for dissolved and atmospheric Nitrous oxide (N_2O) in the North Sea and two East UK estuaries, the Humber and Tweed, are presented. Highest N_2O values were recorded in the low salinity zone (0-2) of the Humber, a well mixed macro estuary, where typical saturations exceed 2000%, relative to ambient air, with maxima over 10000%. This region is a site of active N_2O production throughout the year. Principal production mechanisms are nitrification/denitrification. Seaward of this N_2O production zone , N_2O shows quasi-conservative behaviour. In contrast the Tweed, an unmixed estuary with a residence time of less than two tidal cycles, shows N_2O values close to atmospheric saturation (96-110%) at all sites investigated. Coastal areas exhibited near equilibrium to slight supersaturations (98-125%) with highest levels adjacent to riverine inputs.

MACRO-SCALE VARIATIONS OF pCO_2 DISTRIBUTION ALONG THE BELGIAN COAST

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The macro-scale variations of partial pressure of CO_2 (pCO_2) and related parameters (pH, oxygen, total alkalinity, chlorophyll a and phaeopigments concentrations) were measured in surface water, along the belgium coast, from January 1996 to July 1996, using a fully automated pCO_2 equilibrator. The pCO_2 distribution is dominated by the river input from the Scheldt, that is known to carry highly CO_2-rich water. In Winter, the river Scheldt plume is over-saturated in CO_2 with respect to the atmosphere (around 155%); in Spring and early Summer, important photosynthetic activity, due to the eutrophication, induces under-saturation of CO_2 near the river mouth (ranging from 70% to 90%). Furthermore, the degradation of phytoplanctonic cells, transported by the residual current, induces the over-saturation in the farthest area of the plume. Thus, from one season to another, the river plume acts either as a source or a sink of atmospheric CO_2. On another hand, for all the campaigns, the water outside the river Scheldt plume (Channel water) was under-saturated in CO_2. Further research is needed to determine whether this area acts globally as a source or a sink of atmospheric CO_2.

BIOGAS TRANSFER IN ESTUARIES (BIOGEST*)

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Estuaries are extremely dynamic systems usually characterized by strong physico-chemical gradients, enhanced biological activity and intense sedimentation and resuspension. Estuaries are also subject to intense anthropogenic disturbance such as loadings of detrital organic matter, nutrients and toxic trace elements. All these features increase the potential for biogenic gas production within estuaries. In spite of their potential importance, very little is known about estuaries and their atmospheric coupling. The four objectives of the BIOGEST project are 1) to determine the distribution of biogases affecting climate and atmospheric chemistry in surface water of nine European estuaries, 2) to evaluate the atmospheric biogases fluxes in European estuaries and their impact on the global budget, 3) to understand major biological processes which are responsible for biogases distribution, 4) to develop a predictive biogeochemical model which can be used to relate biogases emission to organic matter and nutrients loadings.
BIOGEST is an EU funded project within ELOISE programme, including 12 European institutions. A general overview of the project is presented.

AIR-SEA CO_2 FLUXES AND COMMUNITY METABOLISM IN CORAL REEFS

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Community metabolism was measured on two barrier reef flats at Moorea (French Polynesia) and Yonge reef (Great Barrier Reef). Gross primary production (P_g) and respiration (R) ranged between 642-1275 and 642-1250 mmol CO_2 m^{-2} d^{-1}, respectively. Both sites displayed a low net primary production. Net calcification (G) ranged from 186 to 253 mmol $CaCO_3$ m^{-2} d^{-1}.
Field measurements of the CO_2 partial pressure (pCO_2) and air-sea CO_2 fluxes showed that both reef flats were sources of CO_2 for the atmosphere (1.8-5.1 mmol CO_2 m^{-2} d^{-1}) because the CO_2 released by calcification was higher than net photosynthetic uptake of CO_2.
Additional measurements carried out on a fringing reef at Moorea showed that an algal-dominated reef flat can behave as a sink for CO_2 (-10 mmol CO_2 m^{-2} d^{-1}) due to the overriding effect of net photosynthesis on net calcification.
The effect of coral reefs on atmospheric CO_2 will be discussed on a global scale.

The importance of aerobic and anaerobic methane oxidation in regulating methane emission from coastal marine areas.

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Methane emission from coastal marine areas is to a large extent regulated by methane oxidation. Anaerobic methane oxidation is quantitatively the most important sink which removes more than 90% of the methane produced in the sediment. The residual methane is still sufficient to generate a large potential sediment water methane flux ranging from 0.008 to 3.1 mmol $m^{-2}d^{-1}$ in Danish coastal areas. A significant part of the potential methane flux is removed by aerobic methane oxidation at the sediment surface. Aerobic methane oxidation rates up to 1mmol $m^{-2}d^{-1}$ have been observed in Danish coastal sediments and on average 50% of the potential methane flux are oxidized at the sediment surface. A minor part of the methane escaping the sediment is oxidized by aerobic methane oxidation in the water column. In total, methane oxidation accounts for a nearly complete removal of the methane produced in these sediments, and only a very minor fraction actually escapes to the atmosphere

NATURAL GAS SEEPS AS SOURCES OF ATMOSPHERIC METHANE: CONTRIBUTIONS FROM EUROPEAN SEAS.

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Natural gas seeps and accumulations of gas in sediments close to the seabed are common features on the continental shelves. The gas is principally methane.
Shallow gas accumulations may be indicated by acoustic turbidity on shallow seismic reflection profiles. On high frequency seismic systems (e.g. echo sounders and 3.5kHz profilers) seeps may be represented by a water column target, however this is dependent upon the resonant frequency, and therefore the size, of the gas bubbles. There may also be confusion between targets presented by fish shoals and seepage plumes, but the former tend to be random in shape and / or horizontally elongate, whereas the latter are vertically elongate.
An indication of the distribution of shallow gas and gas seeps on the European continental shelves is obtained from a review of public-domain seismic profiles (UK waters) and published data (other European waters). This review suggests that seabed gas is widespread, and that gas seeps make a significant contribution to methane concentrations in the water column. Furthermore, modelling suggests that (depending upon bubble size and water depth) a proportion of gas bubbles emitted from the seabed will survive passage through the water column to contribute to atmospheric methane levels. Preliminary estimates suggest that this contribution is comparable to that of other (terrestrial) sources of atmospheric methane.

CHANGES IN THE REDFIELD-RATIOS IN THE ARABIAN SEA

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The biogeochemical cycling in the Arabian Sea is strongly influenced by the seasonal wind-driven up- and downwelling along the Arabian coasts and in the open ocean as well as by the oxidation of nitrate in the oxygen minimum layer north of about 12° N. Based on hydrographic data collected during the METEOR 32 cruises during summer 1995 we investigated the local modifications of the traditional Redfield-Ratio tracers: oxygen, carbon, phosphate and nitrate by applying an OMP water mass mixing model. The classical OMP analysis is expanded by including biogeochemical changes. The mixing of water masses is quantified and compared with results from CFM analysis. The Redfield-Ratios of the Arabian Sea are mapped.

AIR–SEA EXCHANGE OF CO_2, DIFFERENT ESTIMATION TECHNIQUES.

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Air–Sea exchange is usually estimated by the exchange coefficient method and employing the difference in pCO_2 between air and water, measured in specific depth and height.
The validity of this method for inhomogeneous and instationary situations is studied by using a model which solves the numerical diffusion/conservation equation by Fouriertransforming the horizontal variation of the concentration in CO_2. The model takes into account that the carbon content in the water is buffered, that the wind field is instationary, and that heat– and water vapour fluxes can vary with space and time.
Estimation of the fluxes are found in different cases. From the simple case where only the concentration distribution of CO_2 in the water is allowed to vary, to the case where also the instationarity of the wind field, the buffer mechanism in the water and the fluxes of heat– and water vapour fluxes are included. These different cases are compared to see what effects these included mechanism will have on the exchange of CO_2, and it has shown up, that the surface fluxes in instationary and inhomogeneous cases can vary in order of magnitudes compared to the results from the exchange coefficient methods. The output of the model is also compared with resently achieved data from European measurement programs.

THE FORMATION OF LIGHT HYDROCARBONS IN SEA WATER: MECHANISMS AND CONSEQUENCES FOR BIOLOGICALLY ACTIVE REGIONS

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Since several years it is established that ocean surface waters are generally supersaturated with respect to many light hydrocarbons. Thus sea water acts as a source for atmospheric light hydrocarbons. In a number of field and laboratory investigations we studied the concentrations of light hydrocarbons in the surface water of the ocean, the mechanisms responsible for the formation of light hydrocarbons in ocean water and the factors determining the hydrocarbon fluxes between ocean and atmosphere.
In ocean surface waters the most abundant hydrocarbons are light alkenes, especially ethene and propene. Consequently these compounds also have the highest emission rates. Emission into the atmosphere seems to be the dominant loss process for light alkenes from the surface waters of the ocean. Thus emission rates into the atmosphere can, as a first aproximation, be estimated from the oceanic production rates.
The main source of light alkenes in the ocean is photochemical production from dissolved organic carbon (DOC). The production rates depend on the concentration of dissolved organic carbon (DOC) and the irradiation intensity with UV and short wavelength visible light.
Thus it can be expected that marginal seas with high DOC concentrations are substantial sources of light alkenes. However, it should be noted that the penetration depth of light into the ocean will play a key role in the total, column integrated alkene production in the ocean. Since the extinction of light in sea water and the DOC concentration are to some extent correlated, the column integrated alkene production in active coastal zones is not strictly proportional to the DOC concentrations.

Implications of Methane Concentration and Oxidation Rates from a Partially Mixed Estuary on the Atmospheric and Coastal Systems

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Methane is an important greenhouse gas whose mixing ratio in the atmosphere is currently around 1.74 ppmv, and is increasing at approximately 1% a year. In some oceanic environments it has been found to be in equilibrium with respect to the atmosphere while others exhibit typical supersaturations in the order of 130%. Some estuaries have been found to be a major source of methane to the global troposphere and coastal areas. In this paper we describe a 12 month field study of methane concentrations and oxidation rates in the Tyne estuary, in the NE of England. Results show that methane levels were spectacularly high with levels of up to 30000% supersaturation and concentrations ranging from 15 to 1500 nmol l^{-1} with the highest saturations and concentrations found in the lower salinity region of the estuary. Methane oxidation rates, were also found to vary extensively ranging from 0.8pmol $l^{-1}.d^{-1}$ to 195 nmol $l^{-1}.d^{-1}$, with methane concentration being a major controlling factor. These observations will be used to discuss the possible effect of the Tyne estuary to both the atmosphere and local coastal systems.

Carbonyl sulfide photoproduction rates in relation to chromophoric dissolved organic matter distribution in surface seawater

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Carbonyl sulfide (COS) photoproduction rates in North Sea water were determined on samples collected inshore and offshore the island of Helgoland during April 1993. A simple kinetic model including a zeroth order photoproduction constant, surface UV light intensity, and hydrolysis removal satisfactorily describes our results. The mean COS production constants were (2.8 =B1 0.5) fmol liter-1 s-1 W-1 m2 at the inshore station and (1.2 =B1 0.3) fmol liter-1 s-1 W-1 m2 at the offshore station, corresponding to sea surface COS production rates of 0.84 nmol liter-1 d-1 and 0.38 nmol liter-1 d-1 for the inshore and offshore station, respectively. The photoproduction constants normalized to UV absorbance at 350 nm and fluorescence intensity of humic substances were similar for the two sampling stations, indicating that the COS formation is closely related to the concentration of chromophoric dissolved organic matter (CDOM) in seawater. The COS photoproduction rates from this work and a compilation of presently available data show a remarkably high degree of correlation with CDOM absorbance. We propose that the geographical distribution of COS productivity may be extrapolated from remotely sensed CDOM optical properties.

SEA-AIR GAS TRANSFER VELOCITIES IN THE SOUTHERN NORTH SEA MEASURED WITH VOLATILE AND CONSERVATIVE TRACERS : FIRST RESULTS FROM THE ASGAMAGE EXPERIMENT, OCT. 1996.

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During the 1996 "ASGAMAGE" experiment in the S.E. North Sea, gas transfer velocities were determined approximately twelve-hourly over a ten day period, both with the SF_6 / ^3He "dual tracer technique" and individually for SF_6 and ^3He, with corrections for dispersive dilution made with rhodamines WT and G and inert spores of *Bacillus globigii.*. 8 x 10^{14} spores were added to 2250 dm^3 of seawater in a sealed steel tank, with SF_6 and ^3He subsequently added by bubbling. Rhodamines were dissolved separately in 1000 dm^3 of seawater. A five hour, coordinated tracer release into shallow, tidally well mixed waters ~ 20 km off the Dutch coast produced a "tracer patch" ~8 km long, which was labelled with drogued Argos satellite buoys. Continuous underway measurements of SF_6 were used to locate the patch centre, which was sampled routinely for the complete suite of tracers every twelve hours. Windspeed was also monitored continuously. The results allow for the first time, the direct comparison of gas transfer velocities determined at a range of windspeeds with three different combinations of tracers.

Influence of enhanced biological activity on air-water CO_2 exchange in the Scheldt estuary

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It is well known that estuaries are characterized by enhanced biological activity usually due to the presence of high levels of detrital riverine organic matter and nutrients. This is especially true in macro-tidal estuaries where long residence times of water masses can be observed and which are on the other hand often submitted to strong anthropogenic perturbations. This is the case for the Scheldt estuary where we have performed simultaneous measurements of primary production, bacterial respiration and atmospheric exchanges of CO_2. These measurements were carried out over the entire estuary and repeated under various seasonal conditions. Due to the high organic matter load, the upper part of the estuary is dominated all over the year by intensive bacterial respiration, producing anoxic conditions in the water column and pCO_2 levels which may exceed 8000 ppm. This contrasts with the situation at the mouth of the estuary, where the low turbidity and relatively high nutrient content of the water masses intensifies the primary production. Furthermore, the reactive organic matter concentration is reduced to a low level and the bacterial respiration is thus limited near the mouth. The net effect is that during spring and summer, pCO_2 may reach values as low as 100 ppm and thus the mouth of the estuary and the adjacent coastal zone are acting as a sink for atmospheric CO_2.

BREAKING WAVES AND AIR-SEA GAS TRANSFER; THE LUMINY PROJECT.

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The air-sea transfer velocities of gases are only known approximately. Breaking waves are a major but poorly understood factor, but enhance the air- sea exchange of poorly soluble gases by at least three mechanisms: 1) Transfer associated through turbulence generated by breaking waves. 2) Transfer, while gas is within bubbles in the ocean. 3) Transfer across the sea surface when the microlayer has been disrupted by bubbles bursting. These mechanisms are investigated in experiments in the large air-sea interaction simulation tunnel of IRPHE-IOA (Luminy, France) using combinations of aeration devices, mechanical wave generation and wind. A number of gases with widely varying solubilities and molecular diffusion constants have been measured in order to investigate the functional dependence of the transfer velocity. A large number of physical parameters are measured including wind stress, wave characteristics, whitecap coverage and bubble fluxes. The experiments with aeration devices have demonstrated the remarkable efficiency of bubble-mediated transfer (particularly for the least soluble gases) and the ability of bubbles to force the supersaturation of dissolved gases. The experiments with wind and mechanical wave generation have demonstrated the sensitivity of wave breaking to "sea state" at a fixed wind speed. The experiment has elucidated the role of breaking waves in air-sea gas exchange. Once it is recognised that gas transfer velocities are sea state dependent, and this applies both to simulation facilities and the real world, it is necessary to seek practical parameters for predicting transfer in addition to the wind speed or stress. Thus, we must relate gas transfer coefficients to whitecap coverage, bubble statistics or energy dissipation.

MODELING OF THE ANOXIC CONDITIONS FORMATION AND ESTIMATING OF THE DENITRIFICATION RATE AS AN EXAMPLE OF THE BLACK SEA

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The investigations of anoxic conditions in natural waters appears to be very significant because they can be formed both by as natural and anthropogenic ways, as a result of local ecological catastrophes. The one-dimensional model describing nitrogen, manganese and sulfur cycles in suboxic and anoxic conditions is considered. The modeled vertical distributions of nitrogen compounds (total organic nitrogen, ammonium, nitrate, nitrite), dissolved and particulate manganese and inorganic reduced sulfur compounds (hydrogen sulfide, elemental sulfur, thiosulfate, sulfate) as well as dissolved oxygen are adequately corresponded to the observed situation. The model takes into account the processes of turbulent diffusion, sedimentation and biogeochemical transformation of compounds. On the base of the model it was demonstrated, that the anoxic and suboxic conditions form because of organic matter mineralization in condition of restricted oxygen influx. The vertical distribution of rates of sulfur and nitrogen cycles processes were calculated within the frames of the model. According to model the total amount of gaseous nitrogen formation connected with denitrification equals 1 Tg N/yr for all the Black Sea. The model rate of this processes 0.3 mmol/day per square meter can be typical for the regions, where anoxic conditions take place.

OXYGEN DEPLETION IN THE NORTH SEA - AN ANALYSIS OF HISTORICAL OXYGEN DATA

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An extensive analysis of historical oxygen concentration data from the North Sea, spanning the period 1902-1994, was carried out. The data identified areas exhibiting depleted bottom water oxygen concentrations during the late summer, often below ecologically critical levels, some of which were not normally associated with low oxygen events. The data for these regions were subjected to further analysis and the occurrence and severity of oxygen depletion events was shown to differ over a range of spatial and temporal scales through the 92 year period. Results are discussed in relation to hydrography and trends in eutrophication.

OA10/ST22 Sulphur cycle in the marine atmosphere

Convener: Suhre, K.
Co-Convener: Berresheim, H.

TRANSPORT AND OXIDATION OF DIMETHYLSULFIDE OVER ANTARCTICA - RESULTS FROM PROJECT SCATE

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Results from the Sulfur Chemistry in the Antarctic Troposphere Experiment (SCATE) conducted in 1994 suggest the following conclusions: 1. The transport and distribution of DMS over Antarctica is promoted by intense mesoscale storm systems and a relatively long tropospheric DMS lifetime (about 12 days). 2. A significant fraction of DMS may be converted to DMSO and $DMSO_2$ in the Antarctic free troposphere. 3. Measurements of these products and meteorological analyses suggest a sporadic downward mixing of free tropospheric air into the boundary layer. 4. Both DMS products are removed mainly by physical losses. 5. Model calculations suggest that SO_2 was not the major source for observed H_2SO_4 levels.

SULFUR CHEMISTRY OVER THE PACIFIC AND SOUTHERN OCEANS

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Real time measurements of sulfur dioxide were made on board the R/V Discoverer during a transect from Seattle to Hobart, Tasmania and in the Southern Ocean as part of the first IGAC Aerosol Characterization Experiment. Background SO_2 levels increased from 10 ppt at 20°N, to a maximum of 100 ppt at the Equator, then decreased again to 10 ppt in the Southern Ocean. A comparison of background SO_2 with simultaneously measured DMS concentrations shows evidence of anticorrelated diurnal variations at both the equator and in the Southern Ocean. DMS/SO_2 ratios increase dramatically with latitude indicating much higher DMS to SO_2 conversion efficiencies at the equator. The data are examined using simple steady state and photochemical box models and the implications for DMS oxidation chemistry are discussed.

HIGH MSA/NSSSO$_4$ VALUES IN THE ATMOSPHERE AND SNOW AT POLAR LATITUDES: A TENTATIVE EXPLANATION

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DMS oxidation into MSA and SO_2 occurs rapidly in the atmosphere. The further transformation of SO_2 into nssSO_4 may occur either in the gaseous or in the liquid (cloud water) phase, the latter process being considered generally as overwhelming on a global scale. The ratio (R= MSA/nssSO_4) between the mass concentrations of nssSO_4 and MSA varies progressively from about 0.05 at low latitudes up to more than one in sub-Antarctic regions (aerosol and snow measurements). It is commonly put forward that this effect is due to a temperature dependance of the branching ratio of the DMS oxidation process, the formation of MSA being favoured by low temperatures. We propose a mechanism leading to the formation of an "additional" natural source of background sulfate, which would be, in fact, also derived from marine DMS and essentially linked to the extremely cold Antarctic conditions. Our proposal, based on the partial decoupling of the MSA and nssSO_4 atmospheric cycles at high latitudes, would explain the high R values observed in these regions close to DMS source regions, without excluding the temperature dependance of R found at lower latitudes. The phenomenon should also occur in the Arctic.

Uncertainties of DMS concentrations calculated by a global atmospheric circulation-chemistry model

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The Hamburg general circulation model ECHAM coupled to a sulfur chemistry model is used to calculate the distribution of the main atmospheric sulfur compounds. Marine sources of DMS are derived from observed sea-water DMS concentrations applying the approach by Liss and Merlivat to calculate the air-sea gas exchange. Resulting atmospheric concentrations of DMS, SO2 and sulfate are compared to observations. Based on this comparison uncertainties of the source strength and distribution and of the the oxidation pathways are discussed. Additionally, the contribution of marine DMS emissions to the global sulfate burden is estimated.

FLUX OF DMS IN MEDITERRANEAN COASTAL ZONE AND CORRELATION WITH SEA STATE AND FINE PARTICLES.

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DMS is transferred at the sea-air interface and then transformed into particles by gas-particle conversion. It is believed to be the major source of sulphate aerosols in the non-polluted marine atmosphere. These aerosol particles act as cloud condensation nuclei and play an important role in the climate-cloud hypothesis. DMS concentration in the seawater is much greater than in the air, and the transfer velocity depends on molecular diffusivity, wind speed and thermal stability at the sea surface. The presence of whitecaps at the interface considerably enhances the transfer, because they break the laminar surface layer and, when they burst at the surface, each whitecapp air bubble may also transfer gas exchanged in subsurface between water and air bubble. So, the surface sea state must be taken into account to better know the flux of DMS from ocean to atmosphere. Often, coastal zone represents specific cases of sea state, thermal instability and biogenic production of DMS. To study this specificity, DMS concentrations in the coastal zone located of Toulon-Hyères are measured by the cryotrapping-Gas Chromatography-Flame Photometric Detector method. The interpretation of our data is focused on the whitecap cover influence. We use photo and video image processing to quantify whitecap cover area with respect to the meteorological conditions, and try to relate it to the DMS concentration. We present here the first results of both DMS / sea state measurements.

DMS OXIDATION IN THE ANTARCTIC MARINE BOUNDARY LAYER

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Dimethylsulfide (DMS) is thought to be the most important precursor of sulfur oxides and sulfate particles in the Antarctic troposphere. A major objective of the field campaign SCATE conducted in 1994 at Palmer Station, Antarctica, was to clarify those factors controlling atmospheric DMS oxidation by measuring the concentrations of the species DMS, OH, DMSO, $DMSO_2$, H_2SO_4, MSA, NO, O_3, H_2O, and particle number and density. Some interesting case studies are presented here. DMS oxidation in the Antarctic coastal boundary layer was found at times to yield as much MSA as H_2SO_4. Residence times of gas phase MSA and H_2SO_4 were estimated to be less than 2 hours. $DMSO_2$ may not be a major oxidation product of DMSO.

EIGHT MONTHS OF DIMETHYLSULFIDE OBSERVATIONS AT NEUMAYER STATION, ANTARCTICA

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Longterm observations of the aerosol composition in the Antarctic troposphere show a pronounced seasonal cycle of non-sea-salt sulfate and methanesulfonate (MSA). These compounds are produced by the atmospheric oxidation of gaseous dimethylsulfide (DMS). In this contribution we present a record of DMS mixing ratios from a coastal Antarctic site, Neumayer Station (70°S, 8°W), covering a time period of 8 months. Daily measurements of atmospheric DMS started in June 1992 during the polar night and were conducted until February 1993. The DMS mixing ratios range from 0.5 to 75 pptv. The lowest concentrations are found during the period from August to November with an average mixing ratio of 1.0 pptv. In contrast to non-sea-salt sulfate and MSA, the DMS concentrations during the winter months June and July are relatively high and decrease exponentially from 65 pptv to a level of 1.0 pptv in August. The DMS increase was observed in December, which was about 2 months later than the increase of the aerosol species. In January DMS maxima of 75 pptv have been reached. The data suggest an accumulation of DMS in the atmosphere during autumn due to high DMS lifetimes. We assume that this atmospheric reservoir of DMS is the cause for the increase of the non-sea-salt sulfate and MSA concentrations in September. Following the retreat of the sea ice in summer, the importance of local DMS sources increases significantly. A contribution of additional DMS-oxidants apart from the OH-radical, which can explain the exponential decrease of the DMS mixing ratios during the polar night will be discussed.

OXIDATION MECHANISM OF DIMETHYL SULFIDE IN THE ATMOSPHERE : STATUS OF THE KNOWLEDGE

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The oxidation mechanism of dimethyl sulfide (DMS) determines the end product distribution, i.e. SO_2, SO_3 and CH_3SO_3H (methanesulfonic acid, MSA) and, hence, the MSA/SO_4^{2-} ratio, which is crucial for an accurate assessment of the climatic impact of DMS. Laboratory studies have recently provided a lot of kinetic and mechanistic data on the simple steps involved in this mechanism as well as mechanistic information on the overall mechanism. In our laboratory, for instance, data have been obtained recently for the initial oxidation steps of DMS by NO_3, Cl and BrO radicals, and for reactions of the CH_3SO_2 intermediate species (Butkovskaya and Le Bras, J. Phys. Chem. 1994, 98, 2582-2591 ; Butkovskaya et al., J. Phys. Chem. 1995, 99, 4536-4543 ; Bedjanian et al., Int. J. Chem. Kinetics 1996, 28, 383-389 ; Ray et al., J. Phys. Chem. 1996, 100, 8895-8900). Based on these results and those recently published by other groups, it is proposed to present a status of the knowledge, with emphasis on the key steps which influence the end products distribution of the atmospheric oxidation of DMS.

DMS, Aerosols, and Climate: An Update

Meinrat O. Andreae

In their 1987 paper, Charlson, Lovelock, Andreae, and Warren (CLAW) proposed a link between the marine biota, atmospheric chemistry, and global climate. Sulfate reduction by marine micro-organisms results, directly or indirectly, in the formation of volatile sulfur species, the most important of which is dimethyl sulfide (DMS). These volatile compounds escape into the atmosphere, where they are the major natural inputs of sulfur. Atmospheric oxidation reactions result in the formation of sulfate aerosol (and some other oxidized sulfur species), which accounts for most of the sub-micron sized atmospheric aerosol particles and thus most of the cloud condensation nuclei (CCN) in the natural atmosphere. As a consequence, the emission of DMS from the oceans and the resulting modification of cloud optical properties through the production of cloud condensation nuclei was proposed to be a major control on global climate. In spite of intensive study over the last decade, many uncertainties about the CLAW hypothesis remain. The ecological and physiological variables which determine DMS concentrations in the surface ocean, the rate of transfer across the air-sea interface, the mechanisms and sites of new particle production from gaseous sulfur species, as well as the parameters which regulate CCN number concentrations in the atmosphere are still rather uncertain. Progress in this area of research over the last few years will be reviewed and critical problems will be discussed.

PRELIMINARY RESULTS FOR YEAR-ROUND TROPOSPHERIC SO_2 CONCENTRATIONS OBTAINED FROM LOW VOLUME FILTER SAMPLING AT NEUMAYER STATION, ANTARCTICA

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SO_2 is an important intermediate compound in the oxidation chain of biogenic dimethyl sulfide (DMS) with particulate sulfate as the stable end product. In the Antarctic troposphere the aerosol chemistry is characterized by a very distinct seasonal cycle of non-sea-salt sulfate and methanesulfonic acid (MSA), the latter being the only other relevant stable oxidation product of DMS. Since both components are reflecting the DMS emission of a vast area of the Southern Polar Ocean, chemical studies of Antarctic ice cores intend to reveal the long-term changes of the marine productivity. However, the relationship of MSA and non-sea-salt sulfate concentrations is not yet fully understood. SO_2 may play an important role, particularly during transport, as a relatively stable precursor of non-sea-salt sulfate, but not of MSA. Therefore, we started in 1996 a filter sampling program for SO_2 at the air chemistry observatory of Neumayer Station (70°S, 8°W) with the aim of obtaining year-round SO_2 concentrations for the (coastal) Antarctic troposphere. In this contribution, we will discuss the sensitivity of the method and compare the first results with the aerosol chemical composition and DMS concentrations at Neumayer Station.

A CRITICAL ASSESSMENT OF THE CONVERSION RATIO OF SULFUR DIOXIDE TO SULFAT AEROSOL

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In global and regional climate models calculating the sulfat aerosol forcing, a S(IV) to S(VI) conversion of 0.5 has been assumed. The aim of this paper is to show that (a) this conversion rate α is always smaller than 0.5 and (b) that α depends from many factors, which must be included in models decribing the sulfat budget.
It is known from many chemical transformation models which include heterogeneous processes that the S(IV) aqueous phase oxidation within clouds contributes $\geq 90\%$ to the total SO_2 oxidation. Möller and Mauersberger (1992) calculate that the importance of different sulfate formation pathways is dependent on daytime and season, and they suggest that the aqueous phase oxidation is always dominant. For annual averages, however, it is necessary to consider the frequency and duration of clouds (precipitation is negligible in terms of S(IV) oxidation) and the volume of the atmosphere occupied by them. Based on continuous cloud chemistry measurements at Mt. Brocken cloud data which are typical for middle Europe will be presented.
Another important question concerns the function of SO_2 that is dry-deposited because this amount of sulfur is not available to be transformed into sulfate within the atmosphere. A significant share of S(VI) produced in clouds remains on a time average as solute in droplets. Putting all information on S(IV) to S(VI) transformation and the reservoir distribution together we conclude that $\alpha \approx 0.3$.

SOURCES OF AEROSOL NITRATE AND NON-SEA-SALT SULFATE OVER THE EASTERN MEDITERRANEAN

Turkan Ozsoy, A. Cemal Saydam, Nilgun Kubilay, Oya B. Nalcaci and Ilkay Salihoglu

Daily aerosol filter samples collected on the South-Eastern Mediterranean coast of Turkey (360 33'54" N and 34o 15' 18" E) during the October-1991 - December 1992 period were anayzed to determine concentrations for thirteen trace metals and the Cl-, NO3- and SO4= ions. Chemical compositions of these samples along with three dimensional airmass back trajectory analyses revealed that the basin is under the influence of sporadic dust events mainly originated from Sahara. nss-SO4= and NO3- concentrations were relatively low during winter months. The highest nss-SO4= concentrations (20.0 Ug/m3) were measured in spring and early summer months (April-July). The coincidence of highest nss-SO4= concentrations with the periods following high levels of mineral dust suggests that the biogenic DMS was the dominant source of aerosol nss-SO4= in this region.

$nssSO_4^{2-}$, MSA AND THEIR RATIO IN MEDITERRANEAN MARINE AEROSOL

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This work reports preliminary data on the presence of methanesulphonic acid (MSA) in aerosol and rainfall collected in three Mediterranean sites (Italy), one in Sardinia (Torregrande-Or) and two in Tuscany (Leghorn and Florence). The samples were analysed to determine the main and trace components, with particular regard to sulphur biogenic compounds as non sea salt sulphate ($nssSO_4^{2-}$) and MSA. Mean MSA values in rainfall are 9 and 7 μg/l for Torregrande and Florence respectively, while the aerosol mean is approximately 0.01 μg/m³ in both coastal sites (Leghorn and Torregrande). The mean $nssSO_4^{2-}$ concentration values in rainfall are similar for Torregrande and Florence: 2200 and 2500 μg/l. The aerosol median values of $nssSO_4^{2-}$ for Torregrande and Leghorn are 2 and 4 μg/m³. The $MSA/nssSO_4^{2-}$ ratios are lower than 1% for rainwater and aerosol.

AEROSOL COMPOSITION IN THE MARINE BOUNDARY LAYER AND THE FREE TROPOSPHERE AT TENERIFE (28°N, 16°W)

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Aerosol has been sampled using 2 stacked filter packs with a 1.4 µm aerodynamic cut-off at one site in the marine boundary layer (MBL) and one site in the free troposphere (FT) on Tenerife island during July 1996. The samples have been analysed for organic acids, principal anions, and principal cations by ion chromatography. The fine fraction has also been analysed for organic carbon (OC) and black carbon (BC) using a thermal technique. Submicron particle size distributions were measured using differential mobility particle sizers (DMPS). In the MBL (60 m a.s.l.) the coarse fraction was always dominated by sea salt, though non sea salt (nss) Ca^{2+} was observed in most of the samples. The fine fraction was dominated by $nssSO_4$ and associated components, as indicated by the correlation between submicron particle volume and $nssSO_4$ concentration in the fine fraction. However, $nssSO_4$ accounted for only 24% to 52% of the mass during cleaner and polluted periods, respectively. OC and BC contributed for 11-22% and 2-7% to the fine fraction aerosol mass, respectively. In the FT (2360 m a.s.l.), the coarse fraction was always dominated by mineral dust. Preliminary results indicate that even during clean conditions insoluble particles could have been a major component of the aerosol fine fraction as well. Inorganic species (mainly SO_4+NO_3+NH_4) and carboneous species (OC+BC) contributed for comparable amounts to the aerosol fine fraction mass.

MESOSCALE MODELLING OF DMS DURING ACE-1 LAGRANGIAN #B

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We present results from numerical modelling of DMS measurements made during Lagrangian #B of the Southern Hemisphere Marine Aerosol Characterization Experiment ACE-1, that has been conducted in Nov/Dec 95 over the South-west Pacific Ocean, South of Australia. We study the interaction of the different physical and chemical processes controlling DMS in the unpolluted marine boundary layer (MBL), i.e. DMS emission from horizontally inhomogeneous sources, its advective and turbulent transport, entrainment of DMS-poor air into the MBL, and DMS oxidation. Note that the MBL encountered during ACE-1 Lagrangian #B is characterized by warm air moving southward over colder water, resulting in a stable shear-driven MBL, so that the turbulent vertical mixing of the air column is not always complete. The mesoscale meteorological model MésoNH, together with a coupled online chemistry module, is applied to this situation in two configurations: (i) as a 1D moving column model, which is particularly adapted to the Lagrangian measurement strategy, and (ii) as a 3D eulerian model using a horizontal resolution of 20km covering the ACE-1 region.

OCEANIC DMS EMISSION - SIMULATIONS WITH AN OGCM

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Oceanic sulfur emissions as dimethylsulfide (DMS) provide the largest contribution to the natural atmospheric sulfur cycle. Large uncertainties of the magnitude and regional distribution of the oceanic sulfur source exist. Earlier attempts to quantify the oceanic DMS emission were either based on extrapolation of very sparse data or based on correlations of DMS with chlorophyll distributions. We present here results of simulations of the oceanic sulfur cycle with a global three-dimensional biogeochemical ocean circulation model. The model includes a simple plankton dynamic which controls DMS production in sea water. DMS decays via three pathways : bacterial removal, photolysis and exchange with the atmosphere. Simulated DMS concentrations agree, in general, with observations. The model performs similar regional correlations between chlorophyll and DMS as observed. Sensitivity studies with respect to a globally uniform warming by two Kelvin show an increase of the DMS evasion of about 10%.

OA11/ST19 Open session on mesoscale studies

01 Mesoscale meteorology

Convener: Adrian, G.
Co-Convener: Lemaitre, Y.

TRANSPORT PROCESSES OF ATMOSPHERIC POLLUTION IN THE MADRID AIRSHED

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The atmospheric dynamics in the Madrid airshed is governed by thermally induced processes which favours the development of circulations with a marked daily cycle. Four years of intensive experimental campaigns have contributed to characterize the orographic flows, the boundary layer structure, and the mesoscale processes that take place in this part of the Iberian Peninsula. Secondary pollutants have been used as tracers of the airmass transport revealing the magnitude of the space scales involved. These can exceed 100 Km, the distance from the source where the urban plume was detected, and more than 3000 m in height, which is the typical mixing layer depth under strong convection conditions. The role of the topography which delimits the airshed, and specially of the mountain range, has been specially addressed. Mobile units instrumented with ground-based remote sensing sensors, and airborne platforms, have been confirmed as invaluable tools to complement the standard meteorological measurements and air pollution networks, as well as to evaluate modelling results in these type of studies.

MID-LATITUDE CYCLOGENESIS MECHANISMS : A CLIMATOLOGY FROM ECMWF ANALYSES

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Cyclogenesis theoretical models need to be compared with climatological prototypes derived from many cases. To define these prototype cyclones in a relatively objective way, a tracking algorithm is applied to the vorticity maxima encountered in North Atlantic 6-hourly ECMWF analyses. Then a partition of the tracked cyclones is performed. This automatic classification is based on the vertical and horizontal morphology of the events, but also on the time evolution of this morphology. Composite pictures are constructed, mixing the numerous neighbouring cases belonging to the same class. Theoretical models are meaningfully tested against these objective pictures of the reality. With the help of some diagnoses, two important results (among others) are derived from the composite pictures. First, the mechanism of growth is shown to be independent to the mechanism involved in the first appearance of the vorticity maximum. And energetically, baroclinic conversions and kinetic energy dispersion seem to dominate the growth stage.

IDEALIZED NUMERICAL SIMULATIONS OF AIRFLOW IMPINGING ON AN ALPINE-LIKE MOUNTAIN-RANGE

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Meso-scale mountain-barriers like the Alps drastically influence the atmospheric motion. By means of idealized numerical simulations (hydrostatic, adiabatic, inviscid; windspeed, winddirection and static stability constant with height) the flow impinging on an idealized Alpine-shaped mountain (consisting of 27 superposed Gaussian hills) is examined for various angles of the incoming flow to the mountain-range orientation. Situations with and without consideration of the Coriolis effect will be compared. The flow pattern can be explained as a superposition of results for barriers stretched streamwise (aspect ratio $\beta>1$) and spanwise ($\beta<1$) to the initial flow direction. Meridional winds are characterized by strong vertical isentropic displacements connected with foehnic clearing. The highest speeds for winds from S or SW occur north of the Swiss Central Alps, while winds from N or NW produce a maximum south of the Austrian/Italian border. A change of the wind direction resulting in a zonal flow (W or E) leads to a reduction of β and of the Rossbynumber Ro=U/fL (U..windspeed, f...Coriolis parameter, L...moutain length). Therefore the spectrum of the induced waves shifts from vertical and horizontal to mostly horizontal propagation. For a wind impinging from the west the Coriolis force causes an anticyclone with strong winds in the northern Alpine foreland.

MODELLING OF TYPHOON PROPAGATION IN ATMOSPHERE ON THE BASIS OF NONLINEAR SHALLOW WATER EQUATIONS

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The role of singularities for solutions of equations of gas- and hydrodynamics is well known both in the theory of the corresponding equations and in applications. V.P.Maslov established the hypothesis stating that such solutions can describe typhoon and other natural phenomena. A system of two-dimensional nonlinear equations of hydrodynamics ("shallow water"), describing the atmosphere of the Earth in the geostrophic approximation with account of the Earth's rotation is considered. The center of the weak singularity calculated by using the asymptotic representation for a solution of the initial nonlinear system can model the typhoon motion trajectory in the atmosphere of the rotating Earth. By comparising the numerical analysis of weak singularity trajectory with the trajectory motion of the real typhoon "FORREST"(21.09.1983 - 30.09.1983), we observe their quite good qualitative coincidence. This results make it possible to established the following hypothesis. Let us assume that there exists a system of equation that model the typhoon dynamics and let its solutions correspond to a real typhoon. If we know the real typhoon trajectory on a some initial time interval and choose the initial conditions for the corresponding differential equations in such a way that the real and calculated trajectories are close on this initial time interval, then we can suppose that the calculated typhoon trajectory also is close to the real one on the next time interval. This research was supported by the Russian Foundation for Basic Researchers under Grant No.96-01-00937.

MESOSCALE CYCLONES IN THE FRAM STRAIT

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The Fram Strait between Greenland and Spitsbergen is the bottle neck through which the sea ice produced in the Arctic Ocean is exported southward into the Atlantic Ocean. During the field experiment ARKTIS in March 1993 a mesoscale cyclone was observed which developed at the ice edge of the Fram Strait and moved northward over the pack ice. The detection and observation of the cyclone was possible by an array of buoys deployed on the ice and by radiosonde measurements on board RV POLARSTERN. The cyclone was a rather shallow but intense phenomenon; it extended to only 2 km height but was accompanied with low-level wind speeds of up to 20 m/s. The passage of the cyclone had a strong impact on the drift of the sea ice. A similar cyclone event in the same area was reported from the US field experiment CEAREX. It is hypothesized that mesoscale cyclones in the Fram Strait occur more frequently than detected by routine weather analyses and that - by breaking open the pack ice - they play an important role in the regulation of the sea-ice export from the Arctic to the Atlantic Ocean.

MESOSCALE STRUCTURE OF THE FRONTAL SYSTEMS IN THE MEDITERRANEAN SEA FROM THE ERS-1 SCATTEROMETER DATA.

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We present the most interesting cases of frontal systems detected by the ERS-1 scatterometer in the Mediterranean Sea. The data analysed span the period from January 1992 to April 1996. The mesoscale structure of the frontal systems has been studied through the wind field and the structure of the Ekman pumping field, i.e. the vertical velocity of the atmospheric Ekman layer. It has been possible to quantify the frontal activity associated to both the cold and warm fronts, and to detect cases of frontogenesis. In analogy with the spatial pattern of the precipitation, the large and the small mesoscale structures (LMSA and SMSA respectively) have been identified. The selected frontal system cases have been associated to the infrared and visible images provided by the Meteosat and to the cloud coverage provided by the ATSR radiometer of ERS-1. The description of the frontal systems provided by the scatterometer has been compared to that derived from the analysis wind fields of the European centre For Medium Range Weather Forecasting (ECMRWF) of Reading, U.K.. This comparison has allowed a better evaluation of the high level of information which it may be derived from the scatterometer wind fields.

OROGRAPHIC EFFECTS OVER THE ANDES MOUNTAINS PREDICTED USING THE NCEP/UB REGIONAL ETA MODEL

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The Andes Mountains exhibit very narrow east-west extension, but stand over 4000 m in many parts along its north-south extension, causing a strong barrier effect to the westerlies. The subtropical upper level jet crosses the mountains and moves over Northern Argentina at about 30°S. This situation generally occurs when the cold fronts move northeastward. Part of the front crosses the mountains at the southern end where the altitudes are lower. The air descends sharply on the lee side of the mountains causing warming, drying and strong winds, and rises to the original height near South of Brazil. These winds are locally known as Zonda winds. During summer, in the absence of such strong jet crossing the top of the mountains, the air moves smoothly in the horizontal. Both cenarios were forecasted using the NCEP/UB Regional Eta model. This model is running operationally over South America with 40 km horizontal resolution and 38 layers in the vertical. Due to the characteristics of the step-mountain or eta coordinate, the errors in the calculation of horizontal derivatives are reduced, improving the forecasts near the mountain regions. During the cases of strong jets over the mountains the isentropic surfaces can dive from the top of the mountain at about 600 mb to 850 mb in a hydraulic jump resemblance. The phenomenon lasts less than a day, and causes large temperature variation in a day to the villages at the foot of the hills. Stability and turbulence parameters are shown for both cases using model outputs.

FORECAST OF DAILY RAINFALL IN CATCHEMENTS USING MESOSCALE MODEL

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In this study, results relative to the forecast of daily rainfall totals in stations positioned in catchements located in continental Portugal are presented. Forecasts of daily rainfall totals are attempted by using a mesoscale model operating in the Euro-Atlantic sector with initial and boundary conditions provided by a GCM, specifically the RAMS model. Several experiments with RAMS, in an appropriate configuration to continental Portugal, were performed during the winter months of 1989, when days with significant precipitation were observed. It is shown that RAMS model is capable of simulating adequately fields of surface pressure and temperature; however it tends to overestimate relative humidity and wind speed; in general the overall results can be considered reasonable. Regarding precipitation, there is a clear tendency for the dynamic model to forecast correctly the rainfall pattern although rainfall amounts may display, depending on atmospheric conditions, deviations either in point or areal values. Discussion of results and techniques for improvement are offered.

ANALYSIS OF OZONE EPISODES AND THEIR INHERENT STRUCTURE IN SEVERAL LANDSCAPES AT THE SOUTHERN BALTIC COAST

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In previous investigations it was shown that macro-, meso and microscale processes of atmosperic dynamic, natural stock with an anthropogenic and biogenic ozone forming capacity and the mesoscale variability of climatic elements cause a marked differentiation of near ground ozone concentrations within ozone episodes at the southern Baltic coast.
The investigation area with an extent of 80x10 km² is represented by an urban, a suburban and two clean air measurement sites.
In the period from June to August 1995 4 ozone episodes were evident with modifications at every site. Distinct features were the length of daily periods where the critical ozone level 80µg/m³ is exceeded, the daily beginning of this exceedings and the frequence of exceedings during the air-mass climatically determined ozone episodes. Unlike the recommendations of the UN-ECE workshop report on critical ozone levels (1993) we included exceedings of critical levels from 7 am to 9 pm. Measurements at the catena Zingst - Rostock-Holbeinplatz - Rostock-Stuthof - Gülzow showed that 5-20 % of the exceedings started before 8 am. Between 7 am and 9 pm the mean values of ozone concentrations at the clean air sites were above the critical level. The parameters of the stochastic dataset are tested for significance. Significant differentiations of ozone episodes at the 4 measurement sites prove that an adequate network density has to be calculated for an objective assessment of the regional heterogeinity of ozone concentrations in many applications e.g. regional planning, recreation.

ON THE INTERACTIONS BETWEEN TURBULENCE AND MOISTURE PROCESSES AT COLD FRONTS

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Diabatic processes caused by moisture, turbulence or energy exchange with the soil surface bear a significant influence on the shape and development of tropospheric fronts and their weather determining ageostrophic cross frontal circulation. The processes are responsible for the large variety observed at atmospheric fronts. A two dimensional meso-scale model developed for numerical simulations of cold fronts over orography and extended by parameterizations for the warm rain processes and the subscale fluxes is applied to study the nonlinearity of these diabatic processes. Four simulations, starting with the same initial potential temperature and along-front jet fields are carried out. The single effects of moisture (run 2) and turbulence (run 3) show significant differences in the ageostrophic cross frontal circulations compared to the dry adiabatic control run (run 1). In run 2 the updraughts are considerably larger due to latent heat release. Clouds develop in the updraughts of the ageostrophic cross frontal circulation. The turbulence parametrization leads to a strong modification of the jet and an enhanced cross frontal wind in the planetary boundary layer. At least the synergetic effects of turbulence and moisture including the coupling processes (run 4) show the superposition of the single effects as well as the nonlinear additional effect of turbulent moisture transports.

EDDY CORRELATION MEASUREMENTS ON TWO SITES OF SPRUCE POPULATIONS IN THE VOSGES MOUNTAINS (F) AS WELL AS ON ONE SITE IN THE ERZ MOUNTAINS (G)

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Since 1994, eddy correlation measurements based on the eddy correlation/ energy balance method (ECEB) have been carried out within the framework of the REKLIP programme in order to determine the latent heat streams. The measurements have taken place on two 30-year old population sites in the Strengbach (F) catchment area (1000 m a.s.l.). The two sites differ only in population density and in slope orientation and gradient. The resulting variations in real evapotranspiration make it therefore possible to quantify the respective factors influencing evapotranspiration. The simultaneous determination of soil humidity (neutron probe and tensiometer) makes it possible to set up specific reduction functions especially in periods of drouth. The results provide the basis for improved modelling of water and energy balances of forested catchment areas.
Similar measurements have been carried out on a spruce population site at 700 m a.s.l. of the Erz mountains (G). Besides process analysis, these measurements allow for conclusions relating to regionalisation.

KINEMATIC AND THERMODYNAMIC VARIABILITY OF THE ATMOSPHERE OVER NE BRAZIL

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Based on aerological observations of EMAS Experiment (March-April 1995) the diagnostic calculations for the budget components of vorticity, sensible heat and moisture are performed for three stations in the NE Brazil with an average separation of about 300 km. Being only 5° southward from the equator, the region above is characterized climatically as an arid zone with a great year- to-year rainfall variation. The estimations of vertical profiles for adiabatic heating/cooling and for the sources/sinks of vorticity related with mesoscale convective processes are made to study the precipitation mechanism, which is mainly due to short-lived (< 12 hours) and extremly space-concentrated convective disturbances,. The calculations provide a useful means to clarify typical kinematic and thermodynamic structure of the equatorial atmosphere over NE Brazil during rainfall season in terms of vertical velocity, vorticity, horizontal divergence, potential and equivalent-potential air temperature.

THE 'LITFASS' PROJECT OF THE GERMAN WEATHER SERVICE

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LITFASS is an acronym for 'Lindenberg Inhomogeneous Terrain - Fluxes between Atmosphere and Surface: a Long-term Study'. The scientific objective of LITFASS is to determine and to model/parametrize the fluxes of momentum heat, water and other substances, representative for the horizontal scale of the order of 10 km (grid length of the present operational numerical weather prediction (NWP) model DM of the German Weather Service) over heterogeneous land surfaces. A general approach will be to take into account sub-grid scale heterogeneity in the characteristics of the land surface, in the forcing conditions and the resulting fluxes. The LITFASS project is divided into three different sub-projects: Development of an non-hydrostatic model with a grid-size of 100 m, experimental investigations within an 20 km x 20 km area around the Lindenberg Observatory, and data management. The duration of the project is planned from 1995 up to 2000. There is a wide interest for cooperation with research institutes in Germany and in other countries. In this context it is planned to execute an experiment of the BALTEX-Project 1998 in the Lindenberg area using the facilities of LITFASS.

MESOSCALE MODELING OF THE WIND CLIMATE OF IRELAND

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The wind climate of Ireland has been calculated using the Karlsruhe Atmospheric Mesoscale Model KAMM. The climatology is represented by 65 frequency classes of geostrophic wind. They are chosen as equidistant direction sectors and speed classes of equal frequency in a sector. They were carefully selected in order to reproduce the original power of the geostrophic wind distribution. The results are compared with data from the European Wind Atlas (Troen and Petersen, 1989) and newer data for Ireland which has been analyzed using the Wind Atlas Analysis and Application Program WAsP.
The comparison with wind atlas data is fair. The simulations overestimate the wind power at stations with low winds because no daily cycle and thermal forcing was included. Stations with higher wind power than average are better reproduced.
Different frequencies can be asigned to the classes of geostrophic wind using e.g. different years of observations or observed winds from radiosondes and analyzed winds from NWP models as input. Also, this allows to investigate the effects of non-uniform geostrophic wind. Close to mountain ranges the prediceted power is more sensitive to the frequency distribution of geostrophic winds than in flat areas which can be expected.

OROGRAPHIC CLOUDS FORMING IN THE NORTHERN MASSIF CENTRAL

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The Chaîne des Puys is a mountainous barrier in the northern Massif Central (France). The Puy de Dôme, highest point of this barrier (1465m), is place for the European Cloud Ice Moutain Experiment (**CIME**) in winter 1997. For this reason a great number of measurements on atmospheric chemistry, cloud microphysics as well as meteorology will be performed on the summit of the Puy de Dôme. To understand the formation and evolution of orographic clouds forming on the Puy de Dôme, simulations of the flow developing in the northern Massif Central are made. We use the 3D, mesoscale, non hydrostatic Clark Model which has the feature of terrain following vertical coordinate and allows several nested domains to zoom into the area of interest. 3 nested domains are defined: the first (grid=1.8km; dim.=205x158km) includes the north part of the Massif Central in order to well describe the meso-scale environment, the second (grid=600m; dim.=80x80km) allows to study the orographic waves, and the third (grid=200m; dim.=25x20km) zooms in the experimental area and thus allows us to study the local phenomena like orographic clouds and high winds in the lee of the mountains. The results for the wind field are compared with routine wind profiles measurements by a radar ST in the lee of the mountain. The simulated results are furthermore used to initialize the microphysical model **DESCAM** (**DE**tailed **SCA**venging and **M**icrophysics). The microphysical properties of the evolving clouds are compared with first results from the cloud campaign of **CIME**.

2D-AIRFLOW OVER TWIN PEAKS

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Various investigations about the influence of single bell-shaped ridges on the atmospheric flow have been done in the past. For gaining insights into the effect of complex orography on the generation of internal gravity waves, the present work investigates two dimensional flow over a double-mountain profil. As a simplification of the real atmosphere, the initial velocity U and bouyancy frequency N of the inflow are kept constant with height. Numerical results are first compared with existing linear theory for small mountain heights. The simulations are then extended to nonlinear cases with wave-breaking and upstream blocking. Drag varies as function of the distance between the two peaks and the nondimensional mountain height. Wave-breaking above the downslope of *both* mountains occurs only for a critical minimum peak separation. When cold air is blocked on the windward side of the second mountain the maximum of vertical velocity lies just above the upstream edge of the blocked layer. Passing the second peak the flow moves down along the leeslope where strong surface winds are generated.

CLIMATOLOGICAL WIND ATLAS OF THE DARSS-ZINGST-RÜGEN BODDEN-CHAIN IN THE SOUTH-BALTIC SEA

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The climatological wind atlas presents a complete set of simulated regional wind situations, the climatological frequency and mean duration of each situation as well as the mean wind distributions for the various wind directions. The region considered extends over 90 km x 70 km and is situated between Rostock and Bergen/Rügen. The horizontal grid distance amounts to 1 km.
The climatological investigations are based on the long-time series of the wind data at a coastal station. In order to get generalized informations, the data were homogenized and normalized for the local topography. The frequency distribution gives the relative values for each of the simulated wind situations, which belong to fixed geostrophic wind speeds and directions. The geostrophic wind directions are 0, 30, ..., 330°, the speeds are 5, 10, 15, ..., 40 ms^{-1}. The mean duration of persistence is also determined for each class.
For the simulations the non-hydrostatic mesoscale atmospheric model GESIMA in a modified version was applied. Special effort of modification was directed to the inclusion of sea-state and sub-scale roughness-structures as well as to a proper vertical grid resolution. The very shallow numerical grid space of 4 m in the lowest numerical layers enables the internal boundary layers to establish gradually. The thermal atmospheric stratification is supposed to be stable above the mixing layer with mean gradient for all wind directions.

THE MESOSCALE SIMULATIONS FOR THE WIND ATLAS OF THE SOUTH-BALTIC BODDEN LANDSCAPE

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A complete set of stationary states of the atmospheric flow over terrain with complex structures of high roughness-jumps is calculated. The area of the simulations amounts to 90 km x 70 km with a step size of 1 km. The non-hydrostatic mesoscale model GESIMA is applied in a modified version. The modifications enable the model to include subscale roughness-structures, the sea-state in dependence on wind fetch and water depth, to properly account for the inhomogeneous vertical grid spacing, and to adiabatically adapt to the differences in the surface roughness. Moreover, the changes improve the reliability and precision of the calculations. The main modifications in detail are as follows:
1) Determination of an effective scalic roughness-length by area-averaging the subscale surface fluxes based on a blending height.
2) Replacement of the Charnock formula for the roughness of the water surface by a hybrid model depending on the wave height and the ratio between the wave speed and the friction velocity. Both wave heigth and wave speed are affected by the wind speed, wind fetch and water depth.
3) Adiabatical initialization of the local roughness differences.
4) Framing of the region under consideration by addition of two grid points on each side of the horizontal grid.
5) Insertion of a second vertical grid for the quantities describing turbulence.

PV ADVECTION AND THE OMEGA EQUATION

B.J.Hoskins and
D.W.Jones (University of Reading, Dept. of Meteorology, Reading)

PV thinking and the omega equation plus vorticity equation provide two distinct perspectives on the development of mid-latitude weather systems. A third perspective is provided by isentropic relative flow. In this study the three perspectives are united through consideration of the form of the omega equation in which the vertical velocity is split into three parts. The first part is the isentropic upglide. If the system of interest is steady in the coordinate frame used then this describes all the vertical motion. The second part is the vertical motion associated with the differential advection of PV, and the third part is associated with the boundary temperature advection. The analysis will be applied to the Eady model and to isolated PV features to illustrate the relative importance of the various terms and links between the three perspectives of mid-latitude development. The analysis in the presence of diabatic processes will also be discussed.

APPLICATION OF NEW VERTICAL MOTION DIAGNOSTICS

D.W.Jones and
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The theoretical framework in which vertical motion is divided into three components, associated with isentropic upglide, differential PV advection and boundary thermal advection is applied to synoptic features in a baroclinic wave life-cycle and an analysis of an observed mid-latitude cyclone. Viewed in the frame of reference moving with the system , the small amplitude baroclinic wave is dominated by the isentropic upglide, reduced by the boundary thermal advection term. The PV advection term has a weak maximum at the steering level and the tropapause. However in the large amplitude, occluding system the PV advection term becomes much more important. Comparison will be made with the relative importance of the three components in the developing and maturing real system.

THE STRUCTURE OF BAROCLINIC WAVES GROWING ON FRONTAL TEMPERATURE GRADIENTS

M.N. Juckes (Meteorologisches Institut der Universität München)

An analytic, semi-geostrophic, solution for baroclinic waves growing in uniform potential vorticity flow with boundary temperature gradients concentrated in fronts is discussed. The solution has some degree of generality, in that it can be applied to arbitrary frontal surface temperature distributions provided the boundary temperature gradient decreases with distance from the front faster than an inverse cube law. It can be shown that the scaling assumptions which lead to semi-geostrophic theory remain uniformly valid as frontal collapse is approached, even though the along front component of the wind becomes large. This confirms the conclusions of numerical studies by other authors.

MESOSCALE AND MICROPHYSICAL NUMERICAL SIMULATION

Rainbands

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To study winter frontal cloudiness and precipitation a special algorithm for combined using 3-D mesoscale and 1-D microphysical numerical models was developed. The 3-D model is a diagnostic LAM with stretched grid. The resolution in the simulation was varied from 12.5 km near a target area, when rainband passed over it, up to 100 km at the edges of the studied system. The model domain is 1200 x 800 km. The model interpolates data of radiosounds in chosen grid points, gives common description of frontal rainbands' mesostructure and prepares 3-D fields of main meteorological parameters for the microphysical model. The 1-D microphysical model includes detailed descriptions of evolution processes of cloud particles (droplets, raindrops, ice crystals, nuclei, etc.). These processes are generation of cloud particles on CCN and IN, freezing, collection of raindrops and ice crystals for droplets, etc. The 1-D model takes input data from the grid points of the 3-D simulation accounting front's displacing. Thus this combined simulation is more

A GENERAL THEORY FOR OPTIMAL MODE DISTURBANCES IN TWO WAVE SYSTEMS OF BAROCLINIC AND BAROTROPIC INSTABILITY

M.N. Juckes (Meteorologisches Institut der Universität München)

A range of atmospheric instabilities can be described in terms of the interaction between two counter-propagating waves. The simplest example is Rayleigh shear instability, in which the two waves propagate on opposing gradients of vorticity in a barotropic fluid. Another example is given by Eady's model of baroclinic instability, in which the two waves are supported by horizontally uniform temperature gradients on the ground and tropopause. More recently, the author has derived two further analytic solutions. Firstly, for interacting waves on opposing temperature gradients on a single horizontal surface, which can be taken as the ground or the tropopause and, secondly, for waves on the ground and tropopause supported by temperature gradients concentrated into narrow frontal zones. The normal mode approach is applicable when a disturbance has sufficient time to evolve into a fixed spatial pattern. In practice, when the initial amplitude of the disturbance is in the range relevant to atmospheric motions, the disturbance becomes non-linear before this fixed pattern is attained. The amplification of an evolving spatial pattern can be described using the theory of optimal modes. The need to assign a well defined amplitude to an evolving structure introduces a degree of arbitrariness into the theory. Nevertheless, the two-wave problems listed above have a sufficiently simple structure to permit a general solution.

CONVECTIVELY GENERATED GRAVITY WAVES FOUND IN RADIOSONDE DATA

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Gravity waves in the atmosphere can be generated by deep convection as well as by orography. A study has been carried out using radiosonde data to detect the simultaneous occurrence of deep convection in the troposphere and internal waves or inertial waves in the stratosphere. Several months of data from the UK station Camborne (50.2^{0}N, 5.3^{0}W) were used. Convective available potential energy (CAPE) for air parcels lifted from the 850 hPa level was used as an indicator of the likely occurrence of deep convection. Internal gravity waves (short horizontal wavelengths) were detected through their effect on the ascent rate of sondes (typical vertical velocity perturbations are 1 ms^{-1}). Inertial waves or inertio-gravity waves (long horizontal wavelengths) were detected by examining the hodograph (u-v diagram); the waves appear as loops in the hodograph. Cases of correspondence between high values of CAPE and the existence of waves in the stratosphere will be described.

AIRBORNE SEA BREEZE AND COLD FRONT STUDIES IN SOUTH AUSTRALIA

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Several airborne sea breeze (sb) and cold front (cf) measurements between 1988 and 1994 in cooperation with the Flinders Institut for Atmospheric and Marine Sciences (FIAMS) in South Australia were focused on the sensible and latent heat budgets in the vicinity of the front and on the frontogenesis/frontolysis processes. The first missions with a well–instrumented motorglider (Grob G109B), limited on the smaller scale sea breezes, yielded data sets of the frontal structure in the cross frontal direction. The results showed the effects of confluence-generated updraughts, the shear instability causing bulges and clefts in the frontal surface as well as the produced frontal head and the processes related to differential heating and moistening. The following flights with a two-engine aircraft (Cessna 340II) in some cases together with the motorglider gave a larger range of possible measurements. The sb-flights were focused on the improvement of the results and the solution of uncovered problems, like full sea breeze circulations, baby sea breezes, and three dimensional sb-analysis. The cold front research flights with the two engine aircraft shed more light on the shallow cool changes, often observed in Australia. The results show the differences between wide transition zones with a small temperature gradient, but existing over several tens of kilometres and narrow zones with large gradients and strong cross frontal circulations, often connected with severe weather activities.

NUMERICAL SIMULATIONS OF THERMALLY INDUCED CIRCULATIONS FOR THE AREA OF THE GERMAN BIGHT FOR SPRING 1995

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Data from routine weather prediction models are available in a horizontal resolution of more than 10 kilometers. In general, these data do not include mesoscale-γ atmospheric phenomena, caused, for example, by temperature differences between the land and sea surfaces or by tidal influences. However, these mentioned coastal atmospheric phenomena can be incorporated in the data by calculating them with high-resolution atmospheric models.

The results of the Deutschland-model, the high-resolution routine prediction model of the German Weather Service, are used to initialize and to drive the non-hydrostatic mesoscale transport and fluid model METRAS through a one-way nesting method. In this contribution results of both models, METRAS and the driving Deutschland-model, are presented concerning the wind, temperature and humidity fields as well as the surface fluxes of momentum, heat and moisture. The model simulations were performed for the area of the German Bight and the adjacent coastal regions for the measuring period of the KUSTOS-experiment (Coastal Mass and Energy Fluxes — The Land-Sea Transition in the Southeastern North Sea), which took place in spring 1995.

ENERGY BUDGETS OF DRY AND MOIST STATIC ENERGIES OVER THE EURO ATLANTIC REGION FROM A MESOSCALE MODEL

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In this study an attempt is made to identify areas of convective activity, where rainfall can be abundant, using energetic parameters derived from a mesoscale model. The HIRHAM model merges physical parametrizations from ECHAM model with the dynamics of HIRLAM. In this study energy budgets of dry and moist static energies are evaluated using HIRHAM model operating over an area covering North Atlantic, Western Europe and North Africa, driven by the four daily ECMWF analysis (00, 06, 12 and 18 UTC). Precipitation areas are identified from the apparent heat and moisture sources as obtained from model's output. Results are compared with observed distribution of clouds as revealed by satellite imagery, leading to the conclusion that regions of important convective activity, in general associated with frontal systems or isolated depressions as well as with centers of maximum precipitation, are highly spatially correlated with the apparent heat and moist sources.

SIMULATION OF NOCTURNAL DRAINAGE FLOW WITH THE 'LOKAL MODELL'

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The new Lokal Modell (LM) being in development at Deutscher Wetterdienst is a nonhydrostatic model which is intended to be used for a broad range of applications. Among those, for the climate applications, it should be possible to simulate nocturnal drainage flows where the horizontal grid size should be less than 500 m. During cloudless and windless nights drainage flows can form over slopes as a result of the cooling of the earth surface. The rate of production of cold air depends on many parameters like the soil type, the vegetation cover, the terrain inclination... The knowledge of the formation and the behaviour of drainage flows would allow a better regional and urban planning by avoiding the frost over cultured areas but also in respect of the cleaning of overheated and polluted residential areas and transporting of air pollutants. In this work a simulation of such a drainage flow is done with the LM for a valley near Kaiserslautern (SW of Germany). The topographical and land use data are given in a grid size of 40 m, the area contains 115 * 90 grid points. The calculation starts at 21 UTC and is done for 6 hours. This experiment points out the capability of the LM to be used for climate applications in 3-D with a very high resolution and the necessity of further studies, particularly of the effects of the boundary conditions and the land use.

THE STATISTICAL MIXTURE DISTRIBUTION USED TO APPROXIMATE A WINDROSE OF A DEFINED WIND TYPE

Inga Lisac, Ph.D., Assistant Professor
Bogdan Zelenko, Ph.D., Associate Professor
Živko Trošić, M. Sc., Scientific Assistant

Warm, humid and strong wind in the Adriatic sea and coastal area, blowing mostly from southeast quadrant is known under name *jugo*, customarily considered as sirocco. This wind type can be extracted from the entire wind data, by the criteria considering wind direction and velocity intervals, as well as continuous duration above a defined time threshold. Applying so defined criteria the empirical wind rose related to jugo events for a site can be obtained. Such wind roses for three coastal stations were approximated by statistical mixture distribution and described by corresponding parameters. This enables quantitative, objective and simpler comparison of results obtained for several samples.

DOWNSLOPE WINDSTORM-ENHANCEMENT THROUGH MOISTURE?

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When part of the atmosphere becomes saturated, its effective stability and thus the buoyancy-restoring force decrease, which in turn should weaken the wave amplitude and downslope windstorms associated with flow over obstacles, as has been shown in several earlier studies.

This paper applies idealized, two-dimensional numerical simulations of flow over a Gauss-shaped obstacle to show that there exists an exemption to the above conclusion: For certain heights of cloud base high drag states occur for mountains considerably lower than the critical height required in the completely dry case. The necessary conditions and the physical mechanisms involved will be explained in the talk.

NUMERICAL MODELLING OF GRAVITY WAVE DRAG IN THE ISLAND OF MADEIRA

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J. J. Ferreira (Instituto de Meteorologia, Rua C, Aeroporto de Lisboa, Portugal)

In 1993, a field experiment was conducted in the Island of Madeira to measure pressure differences across the island with a set of high precision barographs. The data obtained, for a three-week period during the month of April, was used to infer pressure differences across the island for different background flow. At the same time, local radiosondes profiles, one every twelve hours, surface observations from a small upstream island, and ECMWF analysis for the full period of observations were collected and analysed. These data was used to perform a large number of numerical experiments, using both a simple linear model and a non-hydrostatic non-linear model. Pressure differences obtained with the two models were compared with observations and a number of sensitivity tests were done, to assess the influence of the different input parameters, including the details of the upstream profile and the effect of the transient response to changes in the boundary conditions.

The results obtained may be of interest to gravity wave drag parametrization and also give interesting information on the impact of very disturbed radiosonde data on large scale model analysis.

A SENSITIVITY STUDY ON THE IMPACT OF LANDUSE DATA SETS ON WEATHER PREDICTION

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The impact of landuse data sets on the prediction of the variables of state as well as on the water and energy fluxes was exemplarily investigated by simulations alternatively applying digitized and satellite derived landuse data sets within the framework of a mosaic approach. The fractional coverage of the various landuse types only slightly differs, but the location of occurrence of the landuse shows significant differences within the model domain. Although the distributions of daily averages of temperature and moisture differ less than 0.2 K (1 %) and 0.2 g/kg (1.5 %), respectively, at some location appreciable differences in the daily averages of soil moisture (0.19 m^3m^{-3}, 29 %), soil temperature (2.3 K, 12 %), sensible (30 Wm^{-2}, 29 %) and latent heat fluxes (32 Wm^{-2}, 34 %) occur. During the daytime the area average fluxes of regions dominated by the same landuse in both the data sets differ up to 165 Wm^{-2} (35 %) except for *grassland* for which they are smaller than for all other landuse types. Generally, the greatest differences may occur if a dominance of *grassland* changes to a dominance of *forest* or *settlements* because the surface characteristics differ the strongest for these landuse types. The results suggest that, although on the mesoscale the predicted fluxes significantly differ, on the large scale point of view it only seems of importance that a certain flux occurs within the model domain.

SOLAR ACTIVITY AND TEMPORAL BEHAVIOR OF TEMPERATURE ANOMALIES (GLOBAL AND HEMISPHERIC)

Nataly.M.Astafyeva (Spase Research Institute, Profsoyuznaya, 84/32, 117810 Moscow, Russia)

We study the temporal behavior of Jones's data - the sets of anomalies of the annual average air temperature (global and hemispheric) near the Earth's surface from 1954 to 1990 years. We use Fourier and wavelet transform and correlation technique (for data and for WT coefficients - wavelet spectrum - too). The temporal behavior of global and hemispheric data are qualitatively similar: the scales about 25-30 years separate the small-scale area of the wavelet spectrum (all temporal dynamics are concentrated here) from the large-scale area (the temporal dynamics look like almost linear trend). The main difference between hemispheres - presumabely due to the greater amount of land and stronger anthropogenic factor - being that the warming trend in the Northern hemisphere is slightly stronger and goes first in time. Note that trend (difference between data and the result of opposite WT) have no bend at the begin of our centure. The comparison and mutual correlations with the results of the Wolf numbers analysis offer to investigate in more detail the small timescale area dynamics and connection with Solar activity. There are the correlation with about 11 years cycle (but with the time lag - presumabely due to the inertion of the ocean-atmosphere system) and with about 22 years cycle (the scale slightly larger for Southern hemisphere) and the law level of correlation for the longer timescales.

APPLICATION OF NUMERICAL MODELS FOR RESEARCH OF WINTER FRONTAL CLOUD SYSTEMS

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Two- and three-dimension numerical models of two occluded winter frontal systems passed over Ukraine and two-dimensional model of occluded frontal system passed over USA were considered. Two-dimension model with nested and scretched grids was used to simulate of convective cell embeded in stratiform cloudiness for one case. Simulated atmospheric fronts exhibited many features described earlier for other regions in midlatitudes: hyperbaroclinic zones of different mesoscales, small and large mesoscale rainbands, embeded convective cells, wave-like features of cloud and precipitation evolution and etc.
The precipitable possibility of clouds was defined by dynamical features chiefly. The microphysical mechanisms had crucial role in cloud and precipitation formation if there is lack of their total activity to realize all presipitable moisture.

CLASSIFICATION OF THE ATMOSPHERIC FRONTS ALOFT. HYDRODYNAMIC MODEL OF THE MATURE FRONT

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Analytical model of the atmospheric front based on the linearized equations for horizontal motion and hydrostatic equation is built. The model deals with cold and warm air masses of different and constant potential temperatures separated by the interface. The entire system is set in motion by the external large-scale pressure field and is propagating horizontally at a constant velocity without changing the interface shape. In the coordinate system moving with the front the process is considered as a steady-state. Formulation of the problem for the moving front is possible due to incorporating a neutral logarithmic surface layer in the model so that the non-slip condition at the earth's surface is replaced by a matching condition at the upper boundary of the surface layer. The model is applicable to a mature atmospheric front which can be considered as the final stage of frontogenetical processes. The linearization made in the horizontal equations of motion (it is justified in this problem of a mature steady front where the processes in a tranzitionzone between cold and warm air masses are out of consideration) permits analytical closed-form solution which highlights the basic nondimensional parameters of the problem and enables one to classify solutions. Here we concentrate on the classification of possible types of fronts aloft for which the interface does not intersect the upper boundary of the surface layer. A chart of solutions is built and a stability analysis is used to pick out the front aloft types which can be realized in nature.

INITIALISATION OF A NON-HYDROSTATIC MESO-SCALE MODEL WITH DOPPLER RADAR DATA.

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TOGA/COARE is a project which has been designed to try to understand the role of the warm pool of the Western Pacific Ocean on the Tropical Ocean circulation and its impact on the global atmospheric circulation. It includes an intensive four-months field program (November 1992 - February 1993), during which many observing facilities were deployed. Among those, airborne Doppler radars were involved in aircraft missions to sample mesoscale convective systems (MCS). The kinematic wind-field (3D) that can be derived from the Doppler-radar data provides an extensive survey of the circulation inside the convective system. The aim of this paper is to propose an efficient method to use those data in order to define the initial fields for the mesoscale non-hydrostatic (MESO-NH) model of Centre National de Recherches en Meteorologie (CNRM) and Laboratoire d'Aerologie (LA).

The approach is based on the mesoscale optimal interpolation scheme (CANARI-ALADIN) developed at Meteo-France: radar derived winds, discretized on a 10km grid mesh, are combined with larger scale analyzed fields (guess-field) in order to provide the initial state.

During TOGA-COARE a MCS was sampled on 12 December 1992 from 1800 UTC to 2000 UTC, and then re-observed 24 hours later. Analysis incorporating radar-derived wind is performed for the 12 December 1800 UTC. The mesoscale model is then run over a 24 hour period in order to validate non-hydrostatic simulation against Doppler-radar observations or GMS4 IR satellite images (1800 UTC, 13 December).

VALIDATION TESTS OF A NON-HYDROSTATIC MESOSCALE MODEL

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Pedro M. A. Miranda and M. A. Teixeira (Univ. Lisbon, Centro de Geofisica)

This paper reports on some developments which have been made on the non-hydrostatic NH3D model, initially developed by Miranda and James, at the University of Reading. These developments include the coupling with the ISBA surface model (Noilhan et Planton) and new equations for condensed water and precipitation.
Different validation tests were performed, including several comparisons with published results for flow around idealised mountains with different upstream profiles, in cases where cloud formation or precipitation are expected.
The EFEDA dataset is used to validate the coupling between the atmospheric and the surface model. The problem of initialisation of soil parameters is also addressed with some sensitivity studies, using observational data from a semi-arid region in the South of Portugal.

NUMERICAL MODELLING OF LAKE AND SEA BREEZES

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Rui Salgado (Universidade de Évora)

The present study deals with the problem of the evaluation of the local impact of sea breezes, lake breezes and some non-classical mesoscale circulations. The relevance of these effects is well established, but its real magnitude is largely unknown in the case of small and medium size lakes, irregular coastlines or thermal forcing due to heterogeneities in the land use. The study presents results from a number of numerical experiments for both idealized and realistic surface distributions of the sensible heat flux, including the case of a flat land surface with a simple coastline, the effect of orography, the effect of convergence zones in a convex coastline and the interaction between the couple of breeze circulations produced at the two margins of a mesoscale lake. The well known Florida sea breeze case is used as a validation test for the model. An extension of the linear theory of Rotunno, valid for the case of a mesoscale lake is also presented and its results are found to compare well with non-linear numerical results.

ON THE DEVELOPMENT AND STRUCTURE OF MESO-SCALE VORTICES ON THE TIBETAN PLATEAU

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During summer mesoscale vortices are among the most important rain bearing weather systems on the Tibetan Plateau. Occasionaly these vortices move east, away from the Plateau, and may cause disastrous, heavy rain over parts of China. Due to the scarcity of meteorological observations on the Tibetan Plateau, only little is known about these vortices. In the paper we will, based on results from an extensive series of numerical computer simulations using a high resolution limited area model (HIRLAM), discuss the formation, development and structure of the Plateau vortices. The model simulations indicate that a number of these vortices, contrary to what former believed, initially form as low-level, baroclinic waves. Following the initial development convective processes become increasingly important, although the basic baroclinic structure seems to persist throughout the lifetime of the vortices.

DIAGNOSIS AND NUMERICAL SIMULATION OF A HEAVY PRECIPITATION EVENT IN CATALONIA (SPAIN)

R. Romero, V. Homar, C. Ramis and S. Alonso (Meteorology Group, Departament de Física, Universitat de les Illes Balears, Spain)

A heavy precipitation episode, and subsequent floods, took place in Catalonia (northeastern Spain) on 9-10 October 1994. Most of the coastal raingauges recorded more than 100 mm, and extreme rainfalls exceeded 400 mm at some localities in the south of the region. We present a diagnostical study of the meteorological situation in which the deep and efficient convection developed. The main characteristic at low levels is a southerly low level jet advecting warm and humid Mediterranean air toward the Catalonia coast. At upper levels, a deep trough was present over the southwest of the Iberian Peninsula, producing strong southwesterly winds over the Spanish mediterranean coast and important upward forcing by its vorticity advection. The diagnosis also shows that the coastal topography could have exerted a significant role by focalizing convection. In order to determine the importance of topography for spatial and quantitative rainfall, a hydrostatic mesoscale model with parameterized moist convection has been applied.

THE INTERACTION BETWEEN UPPER AND LOWER-LEVEL POTENTIAL VORTICITY ANOMALIES IN TWO-DIMENSIONAL MODELS.

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The geostrophic momentum approximation is used to investigate the interaction between upper and lower-level tropospheric potential vorticity anomalies, by means of an inviscid, adiabatic and isentropic two-dimensional semi-geostrophic model.The model simulations are intended to address the possibility that an upper tropospheric PV anomaly, moving over a lower-level disturbance, can result in rapid surface cyclogenesis, as well as the possibility that the evolution of the upper tropopause depression and of subsequent stratosphere-troposphere exchanges are linked to the surface developments. The aim of this study is to define appropriate configurations particularly favourable to strong interactions.The baroclinic development is forced by the vertical shear of the geostrophic zonal wind. The initial state is defined given a continuous potential vorticity field, including an upper tropospheric PV anomaly, looking like a tropopause depression, and a lower-level one in the form of a surface pressure anomaly.

The circulation and turbulence structure in mesoscale atmospheric boundary layer over non-uniform surface.

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A method of mesoscale atmospheric boundary layer (ABL) is based on the solution of non-stationary baroclinic closed system, which includes the hydrodynamics and closure equations in topography coordinates to determine the meteorological variables and turbulence parameters. The closure is carried out with the equations of turbulence kinetic energy and its dissipation rate and with Kolmogorov and Smagorinsky relationships for vertical and horizontal coefficients of turbulence. The data of network meteorological information objective analysis in mesoscale resolution near the underlying surface and also of radiozonde observations are used to formulate the vertical boundary conditions. The developed model is applied to the quantitative description of ABL processes in mesoscale over complex topography, urban, suburban and coastal terrain.

THE GAP WIND FRONT OVER A FROZEN LAKE IN A MOUNTAINOUS AREA:

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The flow regime over a frozen lake surrounded by high mountains is studied in a field experiment and simulations with a numerical boundary layer model. It is found that the wind field over the lake in winter is mainly characterised by two flow regimes: forced channelling and pressure channelling or the gap wind.

The gap wind flow, which can give winds in excess of the wind of the top of the disturbed boundary layer, is restricted to the lowest 500 m above the lake surface, drops in speed to zero just above that layer, changing to across wind direction higher up. Gap winds are found to require slightly stable stratification for their existence; strong stability forces the flow to go round the mountains rather than over, and neutral conditions give a turbulent wake in the lee of the mountains. The gap wind starts at any occasion as a sudden warm front approaching from either of the two along wind directions. It is argued that the relatively warmth of the 'gap wind air' is due to air originally flowing at mountain top height across the lake axis being gradually turned and accelerated along the synoptic pressure gradient while descending. It is demonstrated that the prerequisites for a gap wind to occur is not only that the geostrophic wind direction is within certain limits but also that the Froude Number is within certain, well defined limits. This means that for a specific gap wind speed, the temperature difference between the gap wind air mass and the pre-gap-wind air mass must be within certain limits.

AN ENHANCED RESOLUTION ANALYSIS SCHEME FOR THE ATMOSPHERE OVER COMPLEX TERRAIN

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The present analysis scheme has been developed for an automatic and operational recognition of meso scale (meso β) atmospheric patterns over complex terrain. It is based on the determination of the local Laplacian of a scalar field variable. 2D-vector quantities can be treated as well if they are divided into the non divergent and the non rotational part. Due to the irregular spacing of observations and their specific situation with respect to topography (i. e. stations in valleys or basins, on slopes, passes, mountain ridges or peaks) the analysed field usually is very rough. Conventional analysis schemes tend to treat this roughness as noise and smooth it out. Considering the fact that topography actually produces small scale structures of considerable amplitudes these disturbances which are caused by thermal (i. e. elevated heat sources) as well as dynamical (i. e. forced flow over and around the obstacle or blocking) effects of mountains are modelled with the aid of a very high resolution digital terrain data set (horizontal resolution less than 1 km). The modelled thermal and dynamical topographic „fingerprints" are finally used to fit the observations (again the Laplacian) by a mean square method. The resulting fields allow a resolution which is considerably higher than by using observations solely and hence presents a powerful downscaling method. The application of the method in a climatological mode allows in addition to detect even small systematic observational errors.

MEASUREMENTS OF WIND FIELD ON AN EDGE OF A MOUNTAIN RIDGE

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Two field experiments were realized in years 1995-1996 in the Erzgebirge mountain area (north-west part of the Czech Republic). The experiments were aimed to study a variability of the wind speed along a flat mountain ridges. This activity was evoked by tasks associated with optimal location of the wind turbines. Wind velocity was measured simultaneously in two different domains. The horizontal distance between these domains was about 3 km. The first one was located around a small hill (100 m height above surroundings) close to a south-east edge of the main mountain ridge. The second one was selected on the relative flat part of the main mountain ridge, again close to the same edge of the ridge. A horizontal variability of the wind speed between these two areas is studied. It is shown that the ratio of the wind speeds (between two tested domains) essentially depends on wind direction. Experimental data are preprocessed in such a way to serve for validation of numerical models. The second field experiment was oriented to measurements of a detailed structure of the wind field at the second (flat) domain.

PHYSICAL REASONS FOR STRONG HORIZONTAL GRADIENTS IN NOCTURNAL OZONE CONCENTRATION PATTERNS

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It is a well known fact that large differences in ozone concentrations occur during night time in the regional scale close to the surface. Titration of ozone by nonuniform spaced NO emissions and spatial differences of the interaction of advection, turbulent diffusion and deposition are followed by horizontal gradients of the ozone concentration. Numerical simulations with the nonhydrostatic mesoscale model system KAMM/DRAIS were carried out to study how far the nocturnal features of the temporal variation of the ozone concentration can be explained neglecting chemical transformations of ozone and therefore also the impact of emissions. A cross section of the Upper Rhine Valley in the area of Strasbourg was chosen as model domain. Taking into account only physical processes it is found that several observed features of the nocturnal ozone distribution are reproduced to a large extend. An important feature is that the reduction of the ozone concentration in the valley reaches heights up to 500 m above surface in the center of the valley. It will be shown that this is caused by positive vertical velocities in the center of the valley. These positive vertical velocities have an influence on the temperature profile and therefore on the mixing capability of the nocturnal boundary layer.

A STUDY OF THE MESOSCALE CLIMATOLOGY OF THE STABLE BOUNDARY LAYER IN COATS LAND, ANTARCTICA, USING INFRARED SATELLITE IMAGERY.

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Katabatic winds originating in the Coats Land region of eastern Antarctica seldom propagate over the adjacent Brunt Ice Shelf. In an attempt to understand the local dynamics of this katabatic flow infrared satellite imagery covering Coats Land and the Brunt Ice Shelf, were examined together with daily radiosonde balloon flights for the British Antarctic Survey's Halley station during clear sky days in 1993 and 1995. Temperature data from each source were analysed to produce a mesoscale climatology of the stable boundary layer in this region. Satellite data indicate the presence of a 'thermal belt' on the continental slope at a height comparable to the top of the surface inversion over the ice shelf. Above this the surface lapse rate is close to dry adiabatic whilst the free air lapse rate is weakly stable all year round apart from summer. Inversion intensity and thermal belt strength vary dependently throughout the year. The available data have been used to assess the relative importance of some of the forces that control the regional katabatic flow.

CORRELATION OF FLOW IN DIFFERENT VALLEYS

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The atmospheric near-surface flow over complex topography, and mainly in areas with many valleys, is strongly influenced by boundary conditions and is often channeled. Channeling here means that only two preferred wind directions, up- or down-valley, occur. It is our aim to define a measure that allows to quantify to what extent the up- and down-valley flows in different valleys are correlated. For scalar variables, the linear correlation coefficient has proven very useful for a quantitative description of relationships between different variables. For a vector quantity like a wind vector or directional data like wind direction, the definition of a correlation coefficient is much more involved. Many different definitions were proposed for vector correlation and directional correlation. As we are interested in flows with strong channeling, we define a new simple correlation coefficient. It is demonstrated by application to a model of channeled flow that the new correlation captures the flow features in the case of channeling better than other correlations taken from the literature. The new correlation coefficient is used to classify stations in a mesoscale network of anemometers in complex terrain. The stations can be grouped into classes with similar behavior of the channeled flow. Stations belonging to the same class are not necessarily at nearby locations. It is not the horizontal distance, but rather the orographic features and the altitude of the station locations that determine whether two stations belong to the same class and therefore show similar behavior of wind directions.

NORTH ATLANTIC OSCILLATION TYPE AT 500 HPA LEVEL WITH COMPARISON TO NAO INDEX

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The mean monthly values of 500 hPa geopotential heights over Europe and North Atlantic (defined at 80 points of geographical net) were transformed using EOF and varimax rotation to sets of orthogonal variables. These new variables can be interpreted as a characteristic circulation types at 500 hPa level. In each month one of these types corresponds with North Atlantic Oscillations. The variability with time of these types were compared with normalised pressure differences between Ponta Delgada and Stykkisholmur (called NAO index). The correspondence is very high, specially in winter months (correlations of the range 0.8). The maps of loadings were prepared and their interannual variability was analysed. It corresponds with seasonality of two main centres of action: Icelandic Low and Azorian High.

VERTICAL STRUCTURE OF MOUNTAIN WAVES, AND THE EFFECT OF THE TROPOPAUSE.

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Measurements of the vertical wind by VHF radar allow mountain waves to be examined with fine height and time resolutions, and showing the differences in vertical structure associated with trapped or untrapped waves. This study is based on VHF radar measurements of vertical and horizontal wind velocities and echo power, and radiosonde measurements of the temperature height profile. The upward propagation of mountain waves into the stratosphere is investigated with reference to the Scorer parameter profile in the troposphere, and the change in Brunt-Väisälä frequency at the tropopause. Several large-amplitude mountain-wave events, where the wave phase remains nearly constant throughout the troposphere, appear inconsistent with wave trapping below a minimum in the Scorer parameter. Partial reflection at a sharp tropopause may be involved.

PRECIPITATION CHARACTERISTICS OF ~~MESOSCALE CONVECTIVE~~ COMPLEXES IN PEOPLE'S REPUBLIC OF CHINA IN CONTRAST WITH THAT IN THE UNITED STATES

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Eastern region of the Tibetan Plateau, People's Republic of China, is a place where mesoscale convective complexes (MCCs) appear frequently. Here main precipitation characteristics of MCCs in P.R.C. are discussed in contrast with that in the U.S. In P.R.C., 30% to 50% of heavy rainfall (>10mm/h) is caused by MCCs. On average, MCCs produces a rain volume of 2.73 km during their life cycle. Rainfall from MCCs has obvious diurnal variation with the time of maximum at 03LST and minimum at 17LST, 3-4 hours later than U.S. MCCs. During the life cycle, rain volume from MCCs reaches the maximum at the intersection of the developing and mature stages while the strongest rain intensity appears in late initialing and early developing stages. In the initialing stage, rain area coverage increases from a small proportion to about half of the cloud anvil, and almost keep the same percentage through the developing and the mature stages. Some remarkable differences have been fund between the MCCs formed in P.R.C. and U.S. The major rain area of the former is located in the front part with respect to the general direction of MCC movement. The proportion of rain area under the cloud anvil is much larger in Chinese MCCs than U.S. MCCs. The property of transformation from convective to stratiform precipitation during the MCC life cycle is even more obvious.

OA11/ST19 Open session on mesoscale studies

02 Mesoscale transport of pollutants

Convener: Schaller, E.H.
Co-Convener: Mikkelsen, T.

ON THE IMPORTANCE OF AEROSOL PHYSICS AND CHEMISTRY FOR REGIONAL MODELLING; FIRST THREE-DIMENSIONAL RESULTS FROM A MODAL APPROACH.

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The physical characteristics of tropospheric aerosols have to be considered in complex regional chemistry transport models in addition to aerosol chemistry, to obtain a more realistic description of those atmospheric processes that are influenced by aerosols. Hence, a modal approach for modelling coupled aerosol dynamics and chemistry which is fast enough for the use in complex Eulerian transport models is described.

MADE (Modal Aerosol Dynamics model for EURAD) treats aerosol chemistry in the sulfate-nitrate-ammonia and water system. Particle sizes are calculated for two lognormal modes under consideration of nucleation, coagulation, condensation as well as size dependent dry and wet deposition and cloud interactions. First results from a coupled system consisting of MADE and CTM (the chemistry tranport model of EURAD) will be presented. Additionally we will try to identify the most important needs for the future development of this aerosol modelling system.

ON THE MODELLING OF AEROSOL AND PHOTOCHEMICAL SMOG IN BOHEMIAN BASIN

J. Bednar, J. Brechler, T. Halenka (Department of Meteorology and Environment Protection, Faculty of Mathematics and Physics, Charles University, V Holesovickach 2, Prague. Czech Republic)

The transport of air pollution on the regional scale (Bohemian region) is presented. The results of Charles University model for the imission assessment are used to give information on the concentration and deposition fields of aerosol particles. The different spectra of particle size are taken into account. This version of model is based on plume principle and it can be solved both in case of climate studies and actual episodes. The estimation of the real episodes can be support with the computation of other important chemical compounds (nitrogen compounds, VOC's, ozone, etc.) using the new version of the model based on so called puff principle. This version of the model is discussed in more details.

TESTING DIFFERENT PBL PARAMETERIZATIONS FOR MODELLING TRANSPORT AND DISPERSION - VALIDATION FROM THE CHERNOBYL ACCIDENT

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A tracer model for studying transport and dispersion of air pollution caused by a single but strong source is under development. The model is based on a combination of a Lagrangian meso-scale model (RIMPUFF) and an Eulerian long-range transport model (DEM). The Lagrangian model is used in the area near the source to calculate the initial transport and dispersion of the release and the Eulerian model is used for long-range transport calculations in the whole model domain. The meteorological meso-scale model MM5V1 (EURAD-version) is used as a meteorological driver for the transport model. Model simulations from the Chernobyl accident that illustrates the difference of using analyzed fields directly in the tracer model or using the meteorological driver, will be shown. Also different parameterizations of the mixing height and vertical exchange are compared. 2-D and 3-D visualization techniques are important tools for the development and validation of the model results. 2-D and 3-D visualizations together with comparisons with measurements will be shown for Chernobyl.

THE IMPACT OF TRANSPORT FROM NORTH AMERICA ON THE CHEMICAL SPECIES DURING THE NARE 1993 CAMPAIGN, NOVA SCOTIA (CANADA).

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Profiles of O_3, SO_2 and non-seasalt particules SO_4^{--} over the ocean near Nova Scotia, Canada are determined from in-situ measurements made during the 1993 North Atlantic Regional Experiment (NARE). 3-dimensional air back trajectory analyses have shown the high frequency of flow at 925 mb and aloft coming from regions of potentially high anthropogenic sources (North America) and the dominance of flow near the surface originated from maritime regions. Moreover, during the period of Sept. 5-7th, a stratocumulus layer has been formed below 800 m and is going to interact with the chemical products.
The approach used is to assess the impact of clouds on photochemistry. In this aim, using a chemical gas-aqueous phase module coupled with a mesoscale meteorological 2D model (CSU/RAMS), including microphysical processes, and considering variable photolysis rates modified by the presence of clouds, we simulated an episode (Sept. 7th 1993) taken from the NARE campaign. To account for emission flow from the continent, we introduce fluxes for the chemical species on the western boundary in our simulation based on previous studies over the site.
Because of H_2O_2 profiles show a different behavior from the others, hydogen peroxide retains particular attention with the aim of evaluating the relative contributions of varying photolysis rates and of the destruction with SO_2 in aqueous phase.

AIR POLLUTION STUDIES FOR WORST CASE EVALUATION IN THE PLOIESTI-PRAHOVA INDUSTRIAL AREA BASED ON THE RIMPUFF DISPERSION MODEL

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The paper presents the results of research work started at RISOE National Laboratory, Denmark and continued at Petroleum-Gas University of Ploiesti, Romania regarding application of the real-time episode dispersion model RIMPUFF to the Ploiesti-Prahova industrial area with the motivation to understand and quantify severe air pollution scenarios of ground level air concentrations resulting from the different sources of petro-chemical origin located in the industrial area.

Records of one hour mean wind and temperature measurements were taken from the nearby Ploiesti meteorological station and used as input data to the combined flow and diffusion model LINCOM/RIMPUFF for a sequence of severe emissions and wind flow episodes.

Sources were considered inside the Ploiesti industrial area. For the simulations we considered a 50 km x 50 km domain modelled on a 150 x150 grid.

The study encounters some worst case dispersion scenarios in the area, in good agreement with local observations.

On the question of the atmosphere pollution distribution (application for the high relief area)

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The development and distribution of polluted zones (caused by different sources) in the earth atmosphere, is derived from equation of the turbulence diffusion. In the case when the wind velocity component along the pollution distribution and diffusion coefficients do not depends on the altitude, the solution is given by an exponential function. Concentration of the pollution agents depends on the source capacity, wind velocity and air turbulence.
The theoretical results were tested for meteo conditions in Georgia, using the numerical modeling of stationary and nonstationary regimes.
We conclude that pollution agents distribution decrease dramatically crest to the wind velocity, its distribution becoming nearly symmetrical.

MODELIZATION OF THE DISPERSION OF POLLUTANT IN SEA BREEZE FLOW UNDER LARGE SCALE WINDS USING A PARTICLE MODEL.

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An hydrostatic three-dimensional meteorological model (Nickerson et al., 1986) was coupled with a lagrangian particle model (Massons et al., 1996) for analyzing the dispersion of pollutant released by a petrochemical plant on a coastal area considering a constant large-scale wind. The numerical experience covers two complete daily cycles. Results obtained include the overall distribution of particle concentration in each mesh point of the computational domain ($\Delta x = \Delta y = 2.5$ km and 33 levels in height) at each time step (2.5 s for the meteorological code and 50 s for the particle model). The computed meteorological data are compared with measured data, both in surface and in height (using a SODAR Doppler). Computed and measured ground level concentration are compared as well. Authors acknowledge the computer resources provided by CESCA and the finantial support of the Departament de Medi Ambient (Generalitat de Catalunya).

A MIXED-SPECTRAL MODEL FOR MESOSCALE AIR POLLUTION DISPERSION CALCULATIONS

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The fast Fourier transformation (FFT) in horizontal dimensions, applied to the K-theory equation of stationary turbulent diffusion (method earlier used by Beljaars et al for boundary layer flow without admixture diffusion). When applied to the boundary layer over uniform terrain, this approach reduces considerably the range of system of equations to be solved in the numerical scheme (with respect to a gridpooint model). As a result, higher spatial resolution is achieved by equal computing time. The non-physical oscillations, appearing near the points of discontinuity of concentration field (e. g. point sources) due to the FFT, are reduced by the integral transformation of main equation. The similarity theory is used for boundary-layer parametrization. The wind shear effect is included. The model output is compared to the results of a dispersion experiment, carried out by the Norwegian Institute for Air Research (NILU) in a suburb landscape at Lillestrøm 1987. Sonic anemometer and gradient data are used in model evaluation. The intercomparison with models designed at NILU is in progress.

SIMULATIONS AND SENSITIVITY STUDIES WITH THE 'REMO' CEMISTRY MODELLING SYSTEM

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In our contribution we would like to present the latest developments of the global, regional and local scale model hierarchy ECHAM-REMO-GESIMA for the simulation of the troposphere dynamics as well as transport, transformation and deposition of photochemical and acidifying chemical species. The main focus is to couple the models with different scales by "nesting" of the dynamical and chemical variables and to incorporate chemical modules "on-line" in the dynamical circulation models to identify chemical-dynamical feedback mechanisms. Besides the "on-line"-branch, the "off-line"-methodology to determine trace gas distributions in the troposphere has already been established for the regional scale model REMO. Simulations and sensitivity studies of the TRACT'92 episode with a part of the model hierarchy will be shown.

MESOSCALE MODEL OF IMPURITIES TRANSFER

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Numerical mesoscale model of air pollution transport in the interior boundary layer is suggested. The model takes into account all main physical factors, influence to change and transformation of impurities, atmospheric stratification.Trajectories of particles are calculated with main equations of hydrothermodynamics using wind and atmospheric pressure data. The model is applied for assessment of concentrations of such harmful ingredients as sulphur dioxide, nitrogen oxide, carbon dioxide. The model is run for northern region of Russia, which is situated in vicinity of Norilsk mining plant, famous as the largest source of sulphur dioxide. The changes of concentration along the plum are calculated with consideration for dry and wet deposition with different direction and velocity of the winds for 4 seasons.The concentration under unfavourable meteorological conditions is computed as well. We have shown that under these conditions concentration of untoward constituents is much more than tolerable concentration and impurities are spread just by 10 km from the source and are deposit in this region.
We have applied the model for typical town in the European part of Russia (Vladimir). Concentration under unfavourable meteorological conditions here may exceed tolerable concentration by 2.5 times even in this relatively unpolluted town.

BUDGET CALCULATIONS OF PHOTO-OXIDANTS FOR A SUMMER-SMOG EPISODE OVER EUROPE

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The EURAD-model is applied to a summer-smog episode in July/August 1990 to calculate the transport, deposition and chemical transformation of photo-oxidants and their precursors in the troposphere over Europe.

The contribution of the different terms in the continuity equation are analysed for the summer-smog episode considered. Different regions in Europe are investigated and characterized on the basis of mass budget calculations. The processes considered are: transport due to large-scale atmospheric circulation systems, transport due to turbulent mixing, photochemical loss and production, dry deposition, and cloud processes. The sensitivity of the model results and the budget analysis to emissions and boundary values are investigated. The importance of the different processes are compared for different photo-oxidants and their precursors. It could be shown that large-scale subsidence in the high-pressure system, which governed the circulation during that summer-smog episode, play an importa nt role for the mass budget of ozone.

SOURCES OF SO_2, NO_x, SO_4^{2-}, AND NO_3^- IN THE AIR OF LOGROÑO, A SPANISH EMEP STATION

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The sources of SO_2, NO_x, SO_4^{2-} and NO_3^- in the air of a remote station belonging to the EMEP (European Monitoring and Evaluation Programme) network are studied.
To do that we used information about trajectories toghether with the CPF functions (Conditional Probability Functions). Results suggest that the Mediterranean area is the most important source of these pollutants, being also the North of Africa and the South of France important sources for any of the pollutants. The data used correspond to the daily of air composition from January 1989 to December 1994.

NUMERICAL SIMULATION OF THE TRANSPORT OF ATMOSPHERIC TRACE GASES DURING SEA-BREEZE CYCLES IN THE REGION OF SFAX (TUNISIA)

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The transport and diffusion of pollutants in the region of Sfax is studied in typical conditions of sea-breeze development. This local circulation dominates the flow in summer, favouring inland transport of pollutants from the coast. The characteristics of the transport of gaseous pollutants in sea-breeze circulations are investigated using a detailed coupled transport/chemistry mesoscale model (MESONH). We report numerical results of this coupled model about the transport and redistribution of trace gases during successive sea-breeze cycles.

MESOSCALE MODELLING OF SO_2-TRANSPORT IN THE "BLACK TRIANGLE" AREA

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Even if air quality has improved considerably in eastern Germany over the last couple of years, the problem of e.g. SO_2-emission is still an issue especially in the area of southern Saxony (Erzgebirge). Monitoring transport and distribution of SO_2 originating from point and area sources can be supported using the results of mesoscale transport models as additional information.
This paper presents results for SO_2-transport as modelled with the mesoscale transport model METRAS for different meteorological conditions. The simulations refer to the area of the so-called "black triangle". Sensitivity of the results due to different horizontal resolutions as well as to nesting procedures is discussed.

TRENDS AND SEASONAL VARIATION OF SO_2, NO_x, SO_4^{2-} AND NO_3^- CONCENTRATIONS IN THE AIR OF LOGROÑO.

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We have studied the trends and seasonal variation of the concentrations of SO_2, NO_x, SO_4^{2-} and NO_3^- in the air of a Spanish remote station belonging to the EMEP (European Monitoring and Evaluation Programme) network.
This study has been combined with a study of the main geograhycal sources of these pollutants. So we have also done a temporal analysis dividing our sample in subsamples according to the origin of the trajectories. An analysis of the episodicity of high concentrations of these pollutants is also done. The data used correspond to the daily of air composition from January 1989 to December 1994.

VALIDATION OF A PARTICLE DISPERSION MODEL USING DATA FROM THE ETEX EXPERIMENT

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A Lagrangian particle dispersion model, FLEXPART, was recently developed. It is based on model level data from the numerical weather prediction model at the European Centre for Medium Range Weather Forecasts (ECMWF) and is designed to simulate long-range transport processes. It was applied to calculate the transport of an inert tracer released during the first ETEX experiment. The dispersion of the tracer cloud was well simulated, but the model overestimated measured concentrations, especially during the initial phase after the release. Neglection of cloud venting by the model is likely to have caused this bias.

THE PLUME OF VIENNA - COMPARISONS BETWEEN AIRCRAFT MESUREMENTS AND PHOTOCHEMICAL MODEL RESULTS

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In July and August 1995, aircraft measurements were done during episodes of enhanced ozone concentrations around the city of Vienna. One aim of these measurements was to record position, extent and intensity of the urban ozone plume in the lee of the city. For all measurement days, simulated fields of ozone and other pollutants were calculated on a 10x10 km grid covering the region of interest. The simulations were done using the IMPO-model, a Lagrangian box model recently developed at our institute. The back trajectories and meteorological data used by the IMPO-model are based on the data of the ECMWF weather prediction model supplemented by observations from meteorological stations all over Europe. The trajectories around Vienna were corrected by a downscaling approach based on the dense surface wind observation network in Eastern Austria.

The horizontal position of the plume, especially its direction relative to the city centre as recorded by the aircraft measurements, is well reproduced by the model. Downscaling of ECMWF trajectories increases the model performance considerably. The ozone production in the plume is also well simulated. Generally, the IMPO-model performs well in reproducing the position and intensity of the urban plume of Vienna.

FOG MODELING IN THE EURAD-MODEL – A SENSITIVITY STUDY

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A modified version of the EURAD-modeling system has been coupled with an one-dimensional radiation fog model in order to investigate the impact of fog on concentration and deposition fields over southern Germany during an episode from the 15th to the 16th of September 1992. Liquid-phase chemistry transformations and the effects on sedimentation, deposition and the actinic flux are considered within the CFM (Chemical Fog-Module).

Apart from already existing cloud-treatment in the EURAD-System an additional path of sulphate-production and deposition is developed. The resulting SO_2-concentrations are considerably lower in the fog case compared to the base case without fog chemistry. Moreover the photochemical active species are affected by changes in photolysis rates. Not only concentrations of anorganic species such as O_3 but also concentrations of organic species such as Carbonyles reflect the impact of fog on the actinic flux. Due to the predicted fog water concentration the total amount of deposited species increases, e.g. the average amount of deposited H_2SO_4 rises from 6.5 $\frac{g}{ha}$ in the base case to 19.4 $\frac{g}{ha}$ in the fog case.

OA12/ST18 Open session on turbulent boundary layers

01 Basic turbulent studies

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EXPERIMENTS ON A COMPARISON OF TWO REALISATIONS OF THE MELLOR-YAMADA LEVEL 2.5 CLOSURE SCHEME.

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The sensitivity of the Global AGCM [1] to the parameterization of turbulent processes in the boundary layer has been studied. Earlier this model was used with the Helfand and Labraga [2] turbulence package for the boundary layer. Another realisation of the Mellor-Yamada level 2.5 turbulence closure scheme [3] was installed in the AGCM. These packages have been compared using both local 1D and full 3D simulations.

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SPECTRAL GAPS IN THE STABLE FLOW OF A NOCTURNAL GROUND INVERSION

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During a field campaign with the new airborne turbulence measurement system Helipod over a flat region in North Germany a strongly stratified turbulent flow within a nocturnal ground inversion was probed. In the middle of the inversion, in 100 m height, a layer with heavy shear was found. In combination with the suppression of vertical motions and therefore small vertical fluxes this led to small flux Richardson numbers $Ri_f \approx 0.1$. The one-dimensional power spectra of the velocity components and the temperature exhibited gaps with shapes similar to spectral gaps observed in clear air turbulence (CAT). In contrast to CAT the spectral gaps of the nocturnal inversion were found at wavelengths below 10 m. The gap wavelengths were in good agreement with Weinstock's theory (1980) of spectral gaps. Weinstock's predictions could be extended experimentally for temperature and one-dimensional velocity spectra.

TURBULENCE AT A SPLASHING FREE-SURFACE: THE FLOW REGIMES.

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Interactions of turbulence and patches of vortical flow with an air-water interface are analysed. These can be particularly relevant to predict momentum and heat fluxes across the sea free-surface. This is particularly true when subsurface turbulence is so strong to lead to the 'splashing' regime characterised by violent mixing of gas and liquid. A range of flow regimes is inspected to derive a proper scale-dependent description of the interactions. Increasing turbulent intensity leads from a smooth surface first to a rippled surface then clearly developed micro-breaking. Further increases in turbulent intensity lead to air entrainment and drop formation giving a bubbly flow; eventually highly energetic turbulence leads to a splashing regime. We shall use these words: wavy, rippled, micro-breaking, bubbly and splashing to summarise the surface states we discuss. A sixth flow regime can be introduced in which surface deformations caused by patches of vortical or turbulent flow occur in the shape of 'scars'. Hence the name of 'scarified' or scarred. A simple description of the water flow regimes can be achieved in terms of only two main parameters. The first is a typical length λ representing either the size of the turbulent eddies or coherent patches of vortical flow. The other variable used in this discussion is the local turbulent kinetic energy density k defined in terms of the turbulent fluctuations u_i as: $k = \frac{1}{2}\langle u_i u_i \rangle$ where $\langle . \rangle$ is the ensemble average operator. Curves of marginal breaking are discussed in the (k, λ) plane.

COMPARING THE PERFORMANCE OF THE k-ε AND THE MELLOR-YAMADA LEVEL 2.5 TWO-EQUATION TURBULENCE MODELS.

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The aim of the talk is to compare two versions of the k-ε and the Mellor-Yamada level 2.5 two equation turbulence models. Both models include a prognostic equation for turbulent kinetic energy and a length scale related prognostic equation, which in the former case is the dissipation rate of turbulent kinetic energy and in the latter case the product of turbulent kinetic energy and the macro length scale. These models are applied for a 1D numerical simulation of the water column dynamics in the northern North Sea. Wind forced non-stratified and stratified laboratory experiments are used for the calibration. It is shown that the Monin-Obukhov similarity theory is well reproduced by these models as already proved for the algebraic Mellor-Yamada level 2 turbulence closure. The considered turbulence models can in principal simulate the measured thermal dynamics of the upper ocean mixed layer during FLEX'76. It can be shown that the choice of the stability functions which are used as proportionality factors for calculating the eddy viscosity and diffusivity has a stronger influence on the performance of the turbulence model than the choice of the length scale related equation.

WIND WAVE TANK MEASUREMENTS OF BOUND AND FREELY PROPAGATING GRAVITY-CAPILLARY WAVES

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H. Hühnerfuss and P. A. Lange (Inst. für Org.Chemie, Universität Hamburg)

Measurements of the wave amplitude and slope and of the radar backscatter at X and Ka band have been carried out in a wind wave tank with mechanically generated gravity waves as well as with wind generated waves on slick-free and slick-covered water surfaces. The goal of this investigation is to obtain further insights into the mechanisms which are responsible for the water wave damping by monomolecular surface films, in particular, to explain the measured high reductions of the radar backscattering at X and Ka band. Measurements of the radar Doppler shifts show that bound gravity-capillary (X and Ka band Bragg) waves are generated at the crests of steep gravity waves with frequencies between 3 Hz and 5 Hz. Steep 2 Hz waves do not generate bound Ka band Bragg waves. In the whole wind speed range (1.5 m/s to 10 m/s), bound harmonics contribute to the X and Ka band backscatter from a slick-free water surface, whereas their fraction on the backscattered signal depends on radar band and wind speed. Finally, it is shown that a monomolecular surface film has a strong influence on the generation of bound waves. The X band backscatter is mainly caused by bound Bragg waves at wind speeds below 7 m/s, but by freely propagating Bragg waves at higher wind speeds, where the gravity waves are strongly damped by the slick. The Ka band backscatter is mostly caused by freely propagating Bragg waves.

On the existing of the absolutely linear theory for the inamics of the isotropy turbulence

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The classical problem of the theoretical analysis of space-time dynamics of fully developed isotropi turbulence is considered. We prove by using the methods of the double Fourie series that covariance of the simmetrically limited random process with its 2nd degree power is equal zero in the sense of the square-root convergency. As a result, there is a linearity of the Kharman-Howart equation for the velocity fluctuations, and for its spectral analog. Obtained linearity results from the additive character of the Reynold hypothesis. Thus, to take into account non-linearity one has to consider jointly mean flow and fluctuations.

INTERIOR AND BASIN-WIDE DIAPYCNAL MIXING IN STRATIFIED WATER: A COMPARISON OF DISSIPATION AND DIFFUSIVITY

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Turbulence measurements and basin-scale tracer balances have been employed to estimate diapycnal diffusivity in stratified water bodies. As values inferred from these two fundamentally different approaches differ by an order of magnitude in the ocean thermocline, a series of experiments was carried out in order to quantify and to understand the mechanism of diapycnal mixing in an enclosed stratified freshwater basin.

Temperature microstructure measurements in the hypolimnion showed that about 90 % of the turbulent kinetic energy was dissipated within the bottom boundary layer (5 to 10 m thick), whereas only 10 % was lost in the interior of the stratified water body. These findings were corroborated by three fluorescent dye tracer release experiments. Injection of the tracer into the centre of the hypolimnion revealed that the diapycnal diffusivity in the interior was low ($(2\pm0.4)\cdot10^{-7}$ m^2s^{-1}), but increased by an order of magnitude (to $(4\pm1)\cdot10^{-6}$ m^2s^{-1}) upon reaching the sediment boundary. Basin-wide diapycnal diffusivities determined from heat flux measurements agreed well with the results of the vertical tracer experiments after horizontal homogenization.

The consistent results of the two completely independent methods demonstrate that diapycnal fluxes - at least in medium-sized basins - are predominantly generated by mixing within the boundary layer above the sediment.

WAVELET ANALYSIS OF TURBULENCE MEASUREMENTS UNDER STABLE STRATIFICATION

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Turbulence measurements performed in the stably stratified boundary layer (SABL) in Antarctica during the FINTUREX experiment at Neumayer station in 1994 have been analysed by means of the wavelettransformation technique (WT). The SABL supports a variety of turbulent and wave structures of instationary character. Due to its local character the WT has a lot of advantages over the Fouriertransformation for the analysis of these phenomena obtained from turbulence measurements. First results of the application of the WT for the investigation of the turbulent and wave structures are being presented. Furthermore, the associated energy transfer is determined by means of the application of the WT for filtering and conditional sampling.

LAYERED STRUCTURE EVOLUTION IN THE STABLE ATMOSPHERIC BOUNDARY LAYER

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An attempt is made to model the evolution of layered structure associated with strongly stable atmospheric conditions. During the 1986 and 1991 STable Antarctic Boundary Layer Experiment (STABLE) at Halley, Antarctica, a high resolution, monostatic sodar was operated in conjunction with surface-layer turbulence instruments. Multiple layers which persisted for periods of hours to days were observed in the sodar backscatter records. In mast-based temperature measurements, events were observed in which a well-mixed surface layer apparently underwent rapid cooling followed by sudden stratification. Analysis of STABLE kinematic sensible heat flux data suggests that under very stable conditions increasing stablility may act to suppress surface heat flux. A mechanism is suggested through which rapid cooling of the surface brings the atmosphere into the stability regime in which suppression occurs, causing divergence in the heat flux at some height and hence the development of layered structure. A simple 1-D numerical model is presented and used to examine this mechanism.

Turbulent entrainment in atmospheric boundary layer processes

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Modelling turbulent entrainment plays a central role in developing meteorological and environmental models; this paper presents recent research on the mechanisms for different types of situation; in particular entrainment into the sides of growing vertical plumes and clouds and its sensitivity to internal processes, density differences and external turbulence, rates of entrainment at the top of boundary layers and stratus clouds and its sensitivity to internal and external profiles of the buoyancy frequency N.

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ROSSBY VORTICES AND DEFORMATION RADIUS EFFECTS IN PLANETARY TURBULENCE

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The formation of zonal flows and vortices in the generalized geostrophic (or Charney-Hasegawa-Mima) equation in the β-plane approximation

$$\partial_t(\nabla^2 h - L_R^{-2} h) + [h, \nabla^2 h] + \beta h \partial_x h + \beta \partial_x h = D + F$$

is considered. We focus on the regime when the size of structures is comparable to or larger than the deformation (Rossby) radius. In this case an additional nonlinear term $\beta h \partial_x h$, physically analogous to the scalar nonlinearity of the Korteweg-de Vries equation which describes solitons, should be taken into account [1]. The combined influence of the β-effect (both Rossby waves and KdV nonlinearity) and deformation radius on coherent structures is studied. It is shown that for parameters close to those of giant planets large-scale zonal flows created by small-scale forcing tend to preferentially form anticyclonic vortices. Their emergence can be explained by the modified Rayleigh-Kuo instability criterion which takes into account the deformation of free surface. We have provided numerical evidence that for scales larger than the Rossby radius, the scalar nonlinearity is responsible for the formation of ring anticyclonic vortices with quiescent cores consistent with observations of the Jovian and oceanic flows. Physical mechanisms that lead to these phenomena and their relevance to turbulence in planetary atmospheres are discussed.

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ROSSBY VORTICES AND DEFORMATION RADIUS EFFECTS IN PLANETARY TURBULENCE

N. N. Kukharkin and S. A. Orszag (Fluid Dynamics Research Center, Princeton University, Princeton, NJ 08544, U.S.A.)

The formation of zonal flows and vortices in the generalized geostrophic (or Charney-Hasegawa-Mima) equation in the β-plane approximation

$$\partial_t(\nabla^2 h - L_R^{-2} h) + [h, \nabla^2 h] + \beta h \partial_x h + \beta \partial_x h = D + F$$

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MEAN-FIELD HYDRODYNAMICS FOR ROTATING FLUIDS.

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Many turbulent flows that must be understanded are subjected to a rotation. The present study is concerned with Reynolds Averaged Navier-Stockes equations for rotating system with and without convection. There are two basic observations: limited application of the turbulent viscosity hypothesis and possibility for turbulent viscosity became negative in rotating systems. Our prime interest here is with the finding nontrivial parametrisations of Reynolds stresses describing contribution of turbulence to the large-scale momentum flux. Nontrival dynamics of large-scale flows exist when turbulence in rotating system has been treated. It has been found that non-helical component of the turbulent field and the presence of the rotation lead to the additional terms in the Reynolds stress tensor. These terms are proportional to the first spatial derivatives and may cause an additional wave-like transport of momentum. Helical component of basic turbulence leads to the phase velocity difference of such wave-like motions in direct and backward propagating directions. In the presence of convection. described in Boussinesque approximation. we found the possibility for decreasing turbulent viscosity value as compared rotating system without convection.

TURBULENCE STRUCTURE AND LENGTH SCALES IN THE VICINITY OF CIRRUS CLOUDS: OBSERVATIONS DURING ICE AND EUCREX

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Turbulence in the upper troposphere is directly linked to the structure and life cycle of cirrus clouds through internal mixing and entrainment processes. A better understanding of the turbulence structure and dominant scales at cirrus level is of great importance for cloud resolving numerical models and for the development of adequate parameterization schemes for larger scale models. Cirrus clouds cover large areas of the globe and are an important factor in the radiation budget of the Earth. During the International Cirrus Experiment (ICE) and the European Cloud and Radiation Experiment (EUCREX) extended aircraft measurements of turbulence in the upper troposphere were made. Here we will summarize the results and present typical turbulence parameters and length scales for different types of cirrus clouds and background flows. Integral- and buoyancy wavelengths, isotropy factors and spectral characteristics obtain by conventional and wavelet analysis will be discussed.

COOL AND FRESHWATER SKIN OF THE OCEAN DURING RAINFALL

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Rainfall over the sea modifies the molecular boundary layers of the upper ocean through a variety of different effects. These cover the freshwater flux stabilizing the near-surface layer, additional heat flux established due to rain versus surface temperature differences, modification of physical parameters by temperature and salinity changes, enhancement of the surface roughness, damping of short gravity waves, surface mixing by rain, and transfer of additional momentum from air to sea. They are separately described and included in a surface renewal model to investigate the rain's influence on the cool skin of the ocean and the creation of a haline molecular diffusion layer. Simulations with the upgraded model show that the most important effect on the conductive layer is that of enhanced turbulence reducing the surface renewal periods followed by additional surface cooling due to rain on the order of 0.1 K. Comparisons with field data of the cool skin taken during the Coupled Ocean Atmosphere Response Experiment confirm the model results.

Geophysical boundary layer study

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Odessa Hydrometeorological institute

Determination of geophysical boundary layer (GBL) is given. A closed system of hydrodynamics equations is formulated for quantitative description of GBL non-stationary three-dimensional internal structure. Closure of the system is carried out with the turbulence kinetic energy (TKE), dissipation rate (DRE) equations, Kolmogorov and Smagorinsky relationships. The reasons of using TKE and DRE equations in the GBL problem are adduced. The choice of constants in the turbulent characteristics equations is discussed. The boundary conditions for atmospheric and oceanic boundary layers are formulated. The numerical algorithm of the solution the non-linear task is developed. The possibilities of the GBL model to applied problem are demonstrated. As an example, the GBL modelling results over Ukraine for typical hydrometeorological conditions are presented.

COMPARISON OF TURBULENT DISSIPATION RATES MEASURED IN THE BALTIC SEA AND IN ALPINE LAKES

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In 1995 and 1996 several measurement campaigns were made at the Baltic Sea and at Lake Maggiore (North Italy). The microstructure measurements were performed by using the uprising version of the Enhanced Dissipation Profiler EDP, which was developed as a prototype within the EUREKA/EUROMAR project MICSOS. The effects of several wind events are clearly seen in the two dimensional depth-time plot of the measured dissipation rates. The periods with higher turbulence intensity occurred in periods of increased wind speeds. The near surface layer down to a depth of 2 m, with variable and mostly higher dissipation values compared to greater depth, is due to the effect of surface waves. Wind induced Turbulent Kinetic Energy (TKE) production and dissipative loss correlate well. The loss due to dissipation varies between 5 and 15% of the production. The dissipation responds quickly (in less then one hour) with increased values to the on-set of wind events. The observed delay between the termination of the wind driven TKE production and the final decay of turbulence was found to be about 4 hours. In general no "wall layer" profiles were found for the depth decay of dissipation. For wind speeds below 5 m/s the upper layer down to a depth of 2 m beneath the surface shows a z-3 decay, whereas the deeper layer between 7 - 2 m exhibits a linear decrease. It was not possible to confirm the subdivision of the SBL into 3 sublayers proposed by Terray et al. 1996.

EFFECT OF LAGRANGE - SCALE TURBULENCE ON THE POLLUTION INTENSITY OF UNDER-SURFACE ATMOSPHERE FROM GAS-AEROSOL SOURCE.

Volodimir M. Voloshchuk, professor, the head of meteorology and climatology chair of the Kiev T. Shevchenko University

The essential of the research involves direct accounting of Lagrange-scale turbulence L at parametrization of vertical turbulence diffusion of gas-aerosol impurities in the steady field of horizontal wind. The necessity of such clear accounting stems from the fact that at the distance of point source of gas-aerosol impurity R, satisfied the condition of R < 10 H, where H is the height of the boundary layer of the atmosphere, the known condition of feasibility of semiempirical K-theory of turbulent difusion: l>>L, where l - specific scale of non-uniformities of an average concentration of impurities, deliberately is not fulfilled. It was used the hypothesis of delta-correlating of the transferred-by-wind field of vertical turbulent air accelerations. It was shown that the hypothesis gives the distribution of aerosol impurity transferred in the free atmosphere from the point sources, which is satisfactorily matched with the results of full-scale experiments. The integro-differential equations were obtained to account the vertical turbulent flow of gas-aerosol impurities at arbitrary value of relation l/L.

TURBULENT KINETIC ENERGY DISSIPATION IN THE UPPERMOST SURFACE LAYER OF NATURAL WATERS

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The vertical structure of small-scale turbulent mixing in the uppermost surface layer of natural waters is - due to experimental difficulties - whether well resolved nor well understood. As turbulent kinetic energy is often simultaneously produced by wind (due to large scale shear, the action of waves and Langmuir circulation) and by convection as a result of night-time cooling, is has been difficult to separately study the driving mechanisms. In order to evaluate the effect of the different contributions to dissipation ε we analysed experimental observations from a medium-sized lake, taken under different external conditions.

Data has been continuously collected during 12 days in March 1996 in the surface layer of Lake Neuchâtel. The set includes meteorological data, wave gauge and acoustic current measurements, CTD profiles and several hundred profiles of temperature microstructure.

Microstructure-based profiles of dissipation ε, determined for different wind velocities and surface buoyancy fluxes will be presented and compared to theories and analytical turbulence model results.

MIXED LAYER DEPTH AND EKMAN PROBLEM

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The Surface Mixed Layer is studied analytically. It is assumed that the major properties are reflected in a moving slab model of the Kraus-Turner type. The mixing depth and the drift velocity are derived from this consistent model: the Ekman drift for finite depth and the mixing depth for a drifting surface layer are combined. The most important point is the proper treatment of turbulence-producing shear through the mixing layer.

The analytical solutions are discussed. The results are evaluated in conjunction with in-situ measurements of surface fluxes, drift velocity and dissipation profiles.

OA12/ST18 Open session on turbulent boundary layers
02 Studies of atmospheric surface fluxes

Convener: Foken, T.
Co-Convener: Valentini, R.

MEASUREMENT OF FLUXES EXCHANGED BY A FOREST ECOSYSTEM IN ARDENNE'S FOREST

Marc AUBINET (Dept. of Physics, Faculté des Sciences Agronomiques de Gembloux, Belgium)
Narasinha SHURPALI (Dept. of Biologie. Universitaire Instelling Antwerpen, Belgium)

In the frame of the EUROFLUX program (European Community), a set up which measures the fluxes exchanged a forest ecosystem has been erected in Vielsalm (Belgian Ardenne forest). The site is a mixed forest constituted by beeches (*Fagus sylvatica*) Douglas fir (*Pseudotsuga menziesii* (Mirb.)Franco) and Spruce (*Picea Abies*). Fluxes of momentum, sensible heat, water vapour, and carbon dioxide are measured continuously on a half hour basis in using the eddy covariance method. In addition, measurements of air, soil and biomass temperature, air humidity, soil water content, incoming radiation, precipitation, CO2 profiles in the air canopy are performed. We present the results of measurements performed on this site during a first 6 monthes period. In particular the mean daily courses of different fluxes are presented and discussed :

- the energy balance over the site is shown as well as the repartition of available energy between sensible and latent heat flux.
-two independant estimations (by eddy covariance and sap flow measurements) of the water vapour flux are compared
- finally, a first estimation of the net carbon flux is given, and its daily course is discussed in relation with the storage of CO2 in the air inside the canopy.

ENERGY BALANCE CLOSURE AT THE ANCHOR STATION THARANDT

M. Berger, T. Grünwald and Ch. Bernhofer (Institut für Hydrologie und Meteorologie, Technische Universität Dresden, Piennerstr. 9, D-01737 Tharandt, Germany)

Since July 1996 eddy covariance measurements were carried out to estimate the energy and mass fluxes over a spruce forest (*Picea abies*) at a tower of 42 m height. The Anchor station, where the tower is situated, is one location to measure CO_2 and water vapor fluxes within the EUROFLUX project. This projects deal with measurements and process studies to investigate the possible influence of varying CO_2 fluxes and water vapor fluxes in the climate system, especially in the European forests.

Sonic anemometer and close path gas analyzer measurements are made. At Tharandt a high velocity air stream (> 50 l/min) transport the air turbulently in a 59m tube to the measurements hut where a secondary stream probes for H_2O and CO_2 concentrations with 8 l/min. This set-up allows easy access to service the gas analyzer but careful spectral analysis for time lag of wind and scalar signal is necessary. To estimate the fluxes a typical time lag of 10 to 15s was found with two independent methods. All fluxes were also corrected for frequency response. The energy balance closure for the Anchor Station Tharandt could be computed and problems of the closure will be discussed.

SEASONAL VARIATION OF WATER AND CARBON EXCHANGE AT THE ANCHORSTATION THARANDT

Ch. Bernhofer, M. Berger, C. Frühauf and T. Grünwald (Institut für Hydrologie und Meteorologie, Technische Universität Dresden, Piennerstr. 9, D-01737 Tharandt, Germany)

Water vapor and carbon dioxide fluxes of a spruce forest are monitored continuously at the Anchorstation Tharandt as part of the EUROFLUX programme to assess the role of temperate European forests within the global carbon cycle. Based on a site adapted eddy covariance technique (EC, see Berger, M. et al.) water and carbon transport relationships can be established (see Grünwald et al.). To explore the potential to utilize these relationships for a long term assessment of the carbon exchange of the larger forested area *Tharandter Wald* several aspects of turbulent fluxes are addressed: (i) duration and importance of interception, (ii) source areas and (iii) use of the energy balance closure as indicator variable for the applicability of the EC technique.

Data of 1996 show an important role of intercepted water. A changing source area probability was detected that could be categorized in dry episodes, episodes with dominant transpiration and episodes with dominant interception listed with increasing distance to the point of measurement. Energy balance closure was good for unstable and fair for stable stratification. An interception, thermal stratification of the surface layer, and the diurnal/seasonal courses of surface fluxes of gaseous atmospheric constituents are not independent variables. Consequencies for mass balances of these constituents are discussed.

THE INFLUENCE OF VEGETATION COVER ON NIGHTTIME SURFACE TEMPERATURES AND ITS REPRESENTATION IN NUMERICAL WEATHER PREDICTION.

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On radiation nights, when the turbulent fluxes of heat and moisture are negligible, surface temperatures have a dominant influence on the surface layer temperatures. Inaccuracies in the surface temperature can therefore have important impacts on, for instance, fog formation.

Detailed observations of radiation, temperature, humidity, wind and precipitation, collected over a period of three months at MRU Cardington, England, are used to force a model of the surface exchange scheme employed in the UKMO Unified Model. The surface temperatures and fluxes from this model are compared with those measured at the field site over a period of several days.

The results of the comparison show that a layer of vegetation must be included in the surface temperature parametrisation to represent accurately the dominance of radiative fluxes over the ground flux in the energy balance and hence the surface temperature.

AN INVESTIGATION OF THE RELAXED EDDY ACCUMULATION METHOD FOR ESTIMATING ATMOSPHERIC TRACE GAS FLUXES

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The relaxed eddy accumulation method has been increasingly used over the past few years to estimate vertical fluxes of scalars in the atmosphere. It offers a practical alternative to the eddy correlation method when fast-response scalar concentration sensors cannot be used. However, several problems have still to be solved. Firstly, the errors due to the sampling conditions must be quantified since the REA is a 'blind' method. Secondly, little work has been conducted so far on the possible variations of the β coefficient with factors such as atmospheric stability or the characteristics of the distribution functions of vertical wind speed and scalar concentration. Thirdly, there is a blatant discrepancy between the empirical values of β ($\approx$0.56-0.58), as derived from simultaneous eddy correlation measurements, and those inferred from the approximation that the turbulent variables have Gaussian distributions ($\approx$0.62). This paper addresses these issues by using simultaneously two sets of turbulent functions: (1) experimental time series of vertical wind speed and scalar concentrations (temperature, water vapour and carbon dioxide), collected over a pine forest; (2) coherent, correlated functions generated from Fourier spectra with imposed internal characteristics. The values obtained for β confirm previous studies. Stability forces are shown to have a minor effect over the normal range of conditions. However, it is demonstrated that strong asymmetry in the vertical wind speed distribution affects the value of β. The influence of some technical characteristics of the sampling system is quantified (deadband in the vertical velocity, time lag in the tubes, switching frequency...). Guidelines are provided for the design of the sampling system.

SURFACE FLUXES OF NO_2 DETERMINED BOTH BY EDDY-CORRELATION AND VERTICAL GRADIENT METHODS ALONG THE SPANISH COAST

C. Cieslik (Environment Institute, Joint Research Center, Ispra, Italy)

In recent years, surface fluxes of NO_2 represented a matter of discussion since it was not clear whether they were directed down- or upwards. Instrumental artefacts were suspected to alter the data, as well as chemical reactions. This work consists in a series of measurements carried out in parallel with the eddy-correlation and vertical gradient methods over an orange tree orchard along the Spanish coast. The fast-response NO_2 analyser was carefully calibrated and compared with a slow sensor and proved to have a very good performance. Fluxes determined by both methods showed satisfactory agreement; they were directed upwards in low NO_2 regime (see breeze) and downwards in high NO_2 regimes (land breeze). Analysis of the data give clear indications that NO_2 advected from the neighbouring city undergoes deposition; were no advection occurs, upward NO_2 fluxes may be explained by NO emitted by the soil and rapidly converted to NO_2 by chemical reaction.

SPATIAL VARIABILITY OF TURBULENT FLUXES ABOVE A FOREST

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Spatial variability is analysed to validate flux aggregation schemes and to derive corrections for measurements with insufficient fetch conditions. Fluxes of momentum and sensible and latent heat were measured in may and october 1995 at two locations and several heights in a heterogeneous wood in the Netherlands near Veenhuizen. The wood consists of coniferous as well as deciduous species of various height and leaf area index. The shortest distance from the tower to the same forest edge was respectively 50 and 800m. Flux measurements were obtained with a sonic anemometer and a Gill propellor anemometer, in combination with krypton hygrometers and fast response the rmocouples. Variation in the wind direction caused differences in the fetch as well as a different angle of incidence to the forest edge. Flux differences between the two locations are related to differences in species composition as well as to fetch.

LONG TERM MEASUREMENT OF FLUXES OF CARBON DIOXIDE CO_2 AND WATER VAPOUR OVER FOREST

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N. O. Jensen and P. Hummelshøj

A long term monitoring system for fluxes of CO_2 and water vapour, using the eddy-correlation method, is set up in a 57m tall mast in a beech (*Fagus Syluatica*) forest in Denmark. It is part of the EC sponsored EUROFLUX project. It consists of a Gill sonic anemometer and LI-COR 6262 for eddy correlation plus a rang of slow response instruments for profile analysis. Ancillary measurements such as soil humidity and leaf area index are also done. The data are recorded and stored in a local computer but can be transfered from the site to our office by modem at any time. The set up of instruments is described. Roughness and zero-plane displacement are compared by the traditional wind profiles and a simple mass conservation method. Spectra of CO_2 concentration and air humidity are analyzed. The diurnal and seasonal patterns of carbon exchange and evapotranspiration are investigated.

LONG-TERM MEASUREMENTS OF POLLUTANT AND ENERGY FLUXES ABOVE CORN, PASTURE, AND SOYBEANS

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This paper reports on a collection of long-term surface flux measurements of O_3, SO_2, CO_2, and HNO_3 to corn, pasture, and soybeans; the measurement platform; associated surface energy budgets; and the performance of an inferential dry deposition model in predicting deposition velocity (V_d). Fast response O_3, SO_2, and CO_2 instruments coupled with a sonic anemometer were used to derived eddy correlation fluxes for these trace species. A modified Bowen Ratio approach employing filter packs was used to determine HNO_3 flux. Quality control and data assessment procedures are discussed. Flux measurements for O_3, SO_2, and CO_2, are made continuously for up to four months - capturing the total growing cycle for soybeans, a 6-week spring growth spurt for pasture, and a 6-week period of fast growing corn passing to senescence. The major components of the energy budget, ancillary meteorological variables for analysis and modeling, and vegetation parameters, i.e., leaf area index and leaf resistance, were also measured. Fluxes, the energy budget, and observed and modeled V_d are examine for each of the vegetation types, as a function of night and day, and for fast growth and slow growth periods. The magnitude of the fluxes followed the growing cycle with maximum values occurring with fast plant growth conditions and generally large latent heat flux. Measured and modeled O_3 V_d were in agreement for the pasture measurements. Measured O_3 and SO_2 V_d were greater than the model results for corn and soybeans.

ELBDEX96 - COMPARING MICROMETEOROLOGICAL MEASUREMENTS

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Between July and September 1996 ELBDEX96, an extensive micro-meteorological field experiment, was carried out in the Elbe-river-basain close to Lauenburg/Northern Germany. All parameters which contribute to the energy-balance-equation were measured with various instrumentation. Altogether 6 masts of up to 4.5m height were installed to measure the atmospheric parameters. Moreover, 4 spots were selected for the detection of soil parameters. The experimental site was a 50m wide and 70m long smooth field with high grass, which several times a year is overflooded by the Elbe-river. The experiment's aim was the intercomparison of the systems in order to learn more about their reliability during a long-time-study. First selected results are shown, additionally another attempt to close the energy balance equation is performed.

COMPARING TURBULENT FLUX MEASUREMENTS OVER GRASS BY EDDY-CORRELATION AND SCINTILLATION

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During the ELBDEX96 experiment in Northern Germany extensive measurments of sensible and latent heat fluxes as well as momentum fluxes were carried out. In use were 2 Kajo-Denki Sonics and 2 METEK-USATs for eddy-correlation measurements of the fluxes. Moreover, 2 Scintec SLS-20 scintillometers were operated for the indirect path-averaged determination of sensible-heat and momentum fluxes from the turbulent inner scale length and the refractive index structure parameter.The instrumentation was set up on 4 masts at various heights between 1.5m and 4,5m. Depending on the wind direction the overflown soil conditions changed from fairly wet ground conditions to clearly drier ones. First results on the rate of agreement between the different systems at various wind directions will be presented.

PARAMETRIZATION OF FLUXES OVER HETEROGENEOUS MELTING SNOW

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A boundary layer model is used to simulate heat and moisture fluxes over heterogeneous melting snow. Results from the boundary layer model are used to assess predictions of area-average surface fluxes and melt rates from two parametrizations of types used in GCM land surface schemes - an 'effective parameter' model which attempts to calculate average fluxes directly in a single calculation, and a 'tile' model which calculates separate fluxes from snow-covered and snow-free fractions of the surface. Both models give reasonable predictions of average fluxes over cold heterogeneous snow, but the tile model gives much better results for heterogeneous melting snow. Tests using a single-column version of the Hadley Centre GCM suggest that the explicit representation of subgrid heterogeneities in snow cover could have a large impact on GCM surface fluxes.

ATMOSPHERIC TURBULENCE WITHIN A SPRUCE STAND: LONG TERM EDDY FLUX MEASUREMENTS ABOVE A FOREST FLOOR

M. Falk, A. Ibrom, K. Morgenstern, I. Richter, G. Gravenhorst (Institute of Bioclimatology, Georg-August University, Büsgenweg 2, 37077, Göttingen, Germany)

Inside a mature Norway spruce stand in the Solling Mountains an eddy correlation system (METEK, USAT-3 and LICOR LI6262) for the measurement of fluctuations of wind speed, temperature, CO2 and water vapour has been operated since June 1996.

The data was used to examine exchange processes and turbulent regime within the forest. A one way rotation was used and a stationarity test was performed on the data with satisfactory results.

The data was intercompared with data from a second eddy correlation unit above the forest canopy and data measured in the summer of 1995 in Sweden above a forest floor during the NOPEX experiment.

DATA QUALITY ASSESSMENT FOR A LONG TERM EDDY CORRELATION SYSTEM MOUNTED ON A METEOROLOGICAL TOWER ABOVE A FOREST

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Measurements of the fluctuations of wind speed, temperature, CO2 and water vapour have been made above a mature spruce stand (*Picea abies* (L.) Karst.) of 30m height in the Solling Mountains (Germany) since April 1995. The system uses a METEK 3D sonic anemometer (USAT-3) and a LICOR closed path gas analyser (LI-6262) and has been designed for continuous operation. It is mounted towards the west (the main wind direction) at 39m on a 52m tall meteorological tower. A second 3D sonic anemometer (USAT-3, METEK) was added in June 1996 at the same height facing eastward to investigate tower attenuation effects on the measured quantities. A comparison of turbulent parameters as well as a spectral analysis of power- and cospectra were performed on the raw data of the two systems in regard to directional wind classes. For the standard deviation of the vertical wind an attenuation of up to 40 percent was found when the wind crossed through the tower and spectral comparison showed a dissipation effect for vertical wind fluctuations. Other quantities like the temperature fluctuations showed a different behaviour with less or no dependency on wind direction. Due to the damping of the vertical wind component the net fluxes of the other quantities were up to 30 percent lower. Results were used to develop a correction scheme. (a) A correction function for data acquired earlier was determined. (b) The system set-up was changed to accommodate the need for undisturbed data acquisition from all directions.

COMPARISON OF NEW-TYPE SONIC ANEMOMETERS

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As part of the LINEX-96/2 field study (Lindenberg area, Germany) a comparison experiment of different types (mostly new) of sonic anemometers was made. The measurements were done over grassland with a fetch of about 150 m at a height of 2 m. Influences of internal boundary layers were excluded. As a standard device the Kaijo-Denki sonic anemometer type DAT-310 with the Probe A was used. The characteristics of the anemometer are well-known from several experiments. The new CSAT3 anemometer from Campbell Scientific and the USA1 anemometer from METEK GmbH were compared against this 'etalon'. During the comparison experiment the DAT-310 and CSAT3 anemometers were well orientated into the mean wind direction. Differences in the mean wind speeds were not found. The turbulent parameters like standard deviations and fluxes shows specific differences which will be discussed.

COMPARISON OF THE ENERGY BALANCE OVER A MELTING SNOWPACK AS DERIVED FROM PROFILE AND EDDY-CORRELATION MEASUREMENTS

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D. Scherer and E. Parlow (Affiliation as above)

During the snowmelt season 1995 both eddy-correlation measurements of turbulent heat fluxes and profile measurements of air temperature, wind speed and relative humidity were carried out in the Kärkevagge, Swedish Lappland. Additionally, short-wave and long-wave radiation fluxes were measured.
By means of the direct turbulent flux measurements, it's possible to compare the results of different profile methods such as Bowen ratio or aerodynamic method and to test their performance. With regard to the observed meltwater production, the importance of the different terms of the energy balance is examined. However, the aim of this part of the investigations is to decide whether comparatively simple profile measurements allow the proper estimation of the energy balance terms under meteorological conditions causing rapid snowmelt. Moreover, advantages and limitations of the applied methods to determine the energy balance over a melting snowcover are discussed.

EVAPORATION FROM WELL SATURATED SURFACES DERIVED FROM STANDARD METEOROLOGICAL OBSERVATIONS.

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Recently we developed a new method of estimating surface sensible heat fluxes from standard meteorological observations available in many countries throughout Eurasia (e.g., fUSSR, Romania, and China), applied it to studying the snow cover effects on these fluxes, and compared the empirical estimates of these fluxes with the output of several global climate models. Now we discuss our estimates of latent heat fluxes from well saturated surfaces and verify the method by the data of Russian snow evaporation gauges, observations at the heat balance station in subarctic Eurasia, and by the observations at Cabauw, The Netherlands. The analyses of the time series of latent heat fluxes from snow cover over the Northern Eurasia (former Soviet Union) will be presented.

References:
Assessing surface-atmosphere interactions from former Soviet Union standard meteorological data). Part 1. Method (Authors: Groisman P. Ya., and E.L. Genikhovich); Part 2. Cloud and snow cover effects (Authors: Groisman P. Ya., E.L. Genikhovich, R.S. Bradley, and B.M. Ilyin). *J. Climate* (in press).

Surface-level ozone fluxes onto desert sand

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Dry deposition velocities of ozone on soil or bare land, generally used in numerical global or regional models, are taken from data obtained in chamber studies. However, turbulence conditions in the field cannot be truly simulated in a chamber. Since 18 % of all land surfaces on Earth are deserts, there is an interest in quantifying the amount of ozone deposited onto this ecosystem.
Surface-level ozone, the vertical turbulent ozone flux as well as the fluxes of sensible and latent heat were continuously monitored in the Lybian desert, 30 km south of the Dakhla oasis in Egypt from March 23 until April 9, 1993. An automatic station powered by a photovoltaic generator system was used to measure the vertical turbulent ozone flux to the desert ecosystem utilizing the eddy correlation technique. The fairly small ozone fluxes were corrected for effects of micro-turbulent density fluctuations caused by concomittant fluxes of heat and water vapour in the same air volume (Webb correction). While ozone fluxes to the desert ecosystem are below 2 ppb cm s^{-1} in the night, maximum daytime ozone fluxes of 20 ppb cm s^{-1} were measured which yielded a maximum daily dry deposition velocity of 0.15 cm s^{-1}. During the whole measurement campaign of 16 days a mean deposition velocity of V_d = 0.065 cm s^{-1} for ozone is calculated. For global numerical models in which the sources and sinks of ozone in the troposphere are taken into account, a day-time Vd of 0.1 s^{-1} and a night-time value of 0.04 cm s^{-1} are recommended for the desert ecosystem.

TWO METHODS OF DETERMINATION OF THE TURBULENT HEAT FLUX FROM ROUTINE METEOROLOGICAL DATA AND THEIR APPLICATION TO CLIMATOLOGICAL PROBLEMS

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The turbulent heat fluxes at the soil surface are not observed (or poorly observed) by existing observational systems. This affects our ability to reliably predict the consequences of climate changes on the hydrological cycle, to validate corresponding climatic models, and to provide necessary input information for atmospheric dispersion models. Direct measurements of turbulent fluxes in the atmospheric surface layer are available only at a limited number of test sites and for short time periods. Therefore, two methods of determination of the sensible heat flux were developed that utilize the data of routine meteorological observations including, in particular, measurements of the wind speed and air temperature and the temperature of the ground surface. The first method is based on the combination of ideas from the similarity theory and the semi-empirical theory of turbulence. The second method is derived from the similarity theory only. Both methods include description of the "temperature jump" inside the roughness level suggested by Zilitinkevich in 1970. These methods were verified using the data of the observations at Cabauw (the Netherlands), field measurements near Tsimlyansk (Russia), the information from several Russian heat balance stations, and the results presented by Budyko in the Atlas of Heat Balance.

WATER AND CARBON FLUX RELATIONSHIPS - PRELIMINARY RESULTS FROM THE ANCHOR STATION THARANDT

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Since July 1996 continuous measurements of latent and sensible heat, CO_2 and momentum fluxes by the Eddy-Covariance-Method have been made over a spruce forest at the Anchor Station Tharandt, Germany. These flux measurements using a GILL ultrasonic anemometer and a LICOR 6262 CO_2/H_2O gas analyzer are part of the EUROFLUX initiative to monitor water and carbon fluxes of a variety of temporate forests over a broad range of European climate in a standardized manner. All eddy covariance corrections were performed according to state of art (3-axes rotation, frequency response corrections due to deviations from the *ideal sensor*). A typical dependence of net carbon assimilation to primarily photosynthetically active radiation was found and could be used to fill small data gaps. For July and August 1996 a preliminary result shows a net carbon assimilation of 3000 kg/ha which decreases to 700 kg/ha for October and November. Coupling between latent heat and CO_2 flux can be described as a variation between transpiration and net photosynthesis (acc. to Cowan & Farquhar). The optimum is dependent on meteorological conditions like vapour pressure deficit. A parameterisation of canopy resistance of the combination equation is used to model these relationships in dependence on meteorological variables. Preliminary results will be presented.

FIRST FIELD EXPERIMENTS IN THE ARCTIC WITH THE HELICOPTER–BORNE MEASUREMENT SYSTEM HELIPOD

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Results of measurements with the helicopter–carried turbulence measurement system HELIPOD are presented. During the expedition ARK–XI/2 of the german RV „Polarstern“ in autumn 1995, scientific flight missions were conducted in the Arctic. We present results of measurements of turbulent fluxes derived from both horizontal legs and slanted profiles. The lower horizontal legs were flown in heights of 28, 17, and 7 m asl, respectively. During off–ice air flow conditions, we determined rather low values for the heat fluxes over the open water: 10 to 12 W/m^2 for the sensible and 8 to 10 W/m^2 for the latent heat, respectively. The statistical errors estimated from the integral length scales amount to 1 to 2 W/m^2. From the ascends and descends we determined vertical profiles of turbulent fluxes according to LENSCHOW et al. (1988) and TJERNSTRÖM (1993). These profiles were extrapolated to the surface using a simple linear regression. The extrapolated values match well with those derived from horizontal near surface legs.

QUALITY ASSESSMENT AND IMPROVEMENT OF EDDY CORRELATION MEASUREMENTS ABOVE A FOREST CANOPY

A. Ibrom, M. Falk, I. Richter, K. Morgenstern, A. Oltchev, J. Constantin, G.Gravenhorst (Institute of Bioclimatology, Georg-August University, Büsgenweg 2, 37077, Göttingen, Germany)

To analyze the annual budgets of energy and matter fluxes above forest eco-systems and the factors controlling the transport rates, continuous long-term flux measurements are conducted currently (e.g. EUROFLUX). Especially in the case of forests, measurements have been performed within the roughness sublayer. In this presentation we discuss methods to assess data quality and develop improvement strategies for these measurements.
Long term observations of CO_2 and H_2O were performed in the roughness sublayer above a mature spruce forest at the Solling mountains in central Germany. Earlier experiments at the same site showed, that the fluxes were invariant with height in a range from 39m to 51m. To reduce fetch requirements we chose the lowest level for our long term investigation. Thus the system had to be mounted aside the tower oriented to the main wind direction. In order to determine fluxes continuously we investigated the tower effect by means of two sonics mounted in opposite directions. A comparison of the used sonic anemometer (USAT-3, Metek) with two other systems lead to further corrections of the fluxes. Correction of these effects improved the data quality considerably. Site specific quality criteria were defined by statistical characterization of turbulence for a period of more than 18 months. Results were compared to other quality criteria (e.g. energy balance closure) to identify their significance for data quality assessment.

INTERNAL BOUNDARY LAYERS DURING THE LINEX-96/2 FIELD STUDY

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As part of the LINEX-96/2 field study (Lindenberg area, Germany), the characteristics of the Internal Boundary Layers (IBLs) associated with atmospheric flow across a step change in surface roughness from bare soil to grass, in neutral constant stress layers have been investigated using wind and temperature profiles from a 10 m mast. Estimates of the heights of the IBL were obtained as the intersects of the Monin-Obukhov similarity theory derived wind profiles, from below (<2 m) and above (>6 m) the interface. Values estimated within the periphery of the experimental site compared fairly well with existing theoretical/empirical fetch-height relationships of the form: $\delta = a \cdot x^b$, where a, b are empirical constants. Due to influences of distant obstructions (bushes, scattered trees) that was dominant on the air flow along certain wind directions, the ratios of the friction velocity determined clearly indicated the presence of multiple IBLs in the wind profiles examined which depend on the magnitude of the layer-averaged mean wind speeds.

MEASUREMENT OF FLUXES OF MOMENTUM, HEAT, WATER VAPOR AND CO2 OVER WATER BY INERTIAL DISSIPATION AND CO-SPECTRAL ESTIMATION.

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Measurements of surface fluxes are often inhibited by flow distortion and, for may trace gas measurements, low sig/noise and fairly low frequency resolution. These constraints are especially important over the sea, where platform obstruction and motion are facts of life, but will also be important for many over land measurements. Presently is described measurements and dataanalysis from the OMEX measurements conducted from ships over the marginal seas of Europe. The fluxes were estimated from the inertial range of the spectra, using the inertial dissipation method, and simultaneously using the low frequency of the flux co-spectra to confirm the estimates. Inherent low signal/noise ratio for the CO2-measurements was improved by cross- correlating the signal from two instruments. Results from the set-up, that has worked well, is presented and discussed.

COMPLEX TERRAIN SURFACE LAYER PARAMETERS ESTIMATES FOR STABLE CONDITIONS

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Sonic anemometers are well-designed instruments for measuring the turbulent fluxes. From those, the critical surface layer parameters, namely the friction velocity, the Obukhov length and the sensible heat flux, are directly available. For an accurate flux determination, the low frequency contributions arising from non-stationary phenomena such as day/night transition have to be removed. Besides, in complex terrain, one has also to deal with the streamlines curvature. In Payerne, a hilly location, after a cross-validation period at 3 meters, operational measurements have been performed using two sonic anemometers at 3 and 30 meters. The method used to take into account the non-stationary behaviours will be presented. The influence of the topography on the measurements will also be discussed. On the other hand, surface layer parameters using models based on the similarity theory have been computed. Their input data additional to the wind profile are the temperature gradient, the cloud cover fraction associated to the global radiation, and the radiation balance. In the comparison between models and measurements, a particular attention has been given to stable cases.

PROBLEMS IN THE DETERMINATION OF TURBULENT ENERGY FLUXES BY EDDY CORRELATION MEASUREMENTS IN COMPLEX TERRAIN DUE TO WIND FIELD DEFORMATION - A CASE STUDY

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Long-term measurements of surface energy fluxes were carried out on top of a smooth hill which raises up between 10m and 30m above the surrounding terrain. A sonic-anemometer-thermometer was installed to determine the sensible heat flux and the momentum flux as well as a small tower for the mean profiles of wind speed, temperature and humidity. During two days under clear sky conditions with easterly winds between 5m/s and 9m/s one sharp change in wind direction of about 40 degree was observed. Due to a corresponding slight change in the shape of the upwind terrain the friction velocity and the sensible heat flux measured at 3.5m above ground decreased noticeably as a consequence of the deformed wind field which clearly turns out in the wind profile. Statistical analyses under neutral conditions show a strong dependence between the wind direction i.e. the shape of the terrain and the mean vertical wind component and the friction velocity, respectively. With this information errors in the measured sensible heat flux can be estimated and a correction can be applied to the data. A mean closure gap in the energy balance was found which possibly is related to an underestimation of the sensible heat flux due to the wind field deformation.

USING CBL BUDGETTING TO ESTIMATE TRACE GAS FLUXES AND ISOTOPIC FRACTIONATIONS ABOVE A FOREST/BOG COMPLEX IN CENTRAL SIBERIA

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Six airplane flights were undertaken above and within the convective boundary layer over a bog/coniferous forest complex in Central Siberia (61 N 90E) in July 1996. As well as continuous measurements of temperarure, pressure, and the concentrations of carbon dioxide and water vapour, about 10 flasks were also filled per flight for measurements of methane, carbon monixide, hydrogen and nitrous oxide as well as for the carbon and oxygen isotopic composition of CO2. Despite considerable input of sensible heat from the forest below, the CBL did grow to more than 1200 m, reaching this height before noon. Available meteorological data suggests that considerable subsidence occurred and this appears to be a regular and widespread phenomenon of this continental region. Substantial changes in the concentration of all gases except N20 occurred near the entrainment zone of the CBL, with differences between CBL air and that of the free troposhere above being as high as 10 ppm for CO2 and 50 ppb for CH4. Regional fluxes were estimated from these profiles and the estimated rates of entrainment and subsidence. The subsidence term was very significant and even resulted in the concentrations of CO2 increasing in the CBL in the afternoons, despite removal of CO2 from the CBL by the photosynthesing vegetation below. Regional estimates of photosynthetic fractionations for carbon-13 and oxygen-18 in CO2 are also presented.

THE MODELISATION OF THE CARBON, WATER AND HEAT EVOLUTION AND DISTRIBUTION IN A FOREST CANOPY

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The purpose of FOREM (FORest Exchange Model) is to reproduce the variations of different forest pool contents in the carbon, water and energy balances and to predict the fluxes between these pools on a hourly basis. To reach these goals, a mechanistic model is built with three components: the air of the canopy, the vegetation and the soil on a spatial scale of approximately one hectare. The atmosphere and subsoil are the upper and lower boundaries of FOREM. The calibration and validation of this model is performed on measurements taken by M. Aubinet in a beech canopy at Vielsalm (Belgium). This Euroflux site is also equiped with an eddy covariance flux mesurement system that allow us to compare the net fluxes released by the beech canopy with those calculated by FOREM. The objectif of obtaining a validated model forces us to limit the number of pools and the description of fluxes. The first step of this study is the determination of the pool number and flux parameterization most appropriate for the Vielsalm forest canopy. Several parameterizations and schemes are tested, for each components of the hydrological model. The flux estimates resulting from these simulations are compared as much as possible with mesurements.

MEASURING MASS AND ENERGY FLUXES OVER A TEMPERATE BEECH FORESTS: METHODS, PROBLEMS AND RESULTS

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Since 1991, a long-term monitoring station have been installed in a beech forest in Central Italy (Collelongo, 1500 m a.s.l., 41°52N 13°38E). Structural, micrometeorological and ecophysiological traits have been measured, together with hydrological balance components.
Since 1993, eddy covariance measurement have been performed, using a Gill-Solent sonic anemometer (Gill, UK) and a closed-path IRGA (LiCor 6262, LiCor, USA). Mass (CO_2/H_2O) and energy (sensible and latent heat, net radiation) fluxes have been measured over the forest for almost 2.5 years.

Methods and problems will be discussed with particular regards to: i) technical (hardware, software, etc.) and logistic difficulties in implementing long-term measurements in a remote and mountainous site; ii) problem solving.

Results will be presented in terms of: i) energy balance closure (eddy fluxes and net radiation); ii) quality check of the data (acquisition delay between sonic and IRGA, post-processing of the data, footprint analysis); iii) missing data interpolation; iv) seasonal budget

Hints and highlights will be critically given making profit of this 6 years experience.

COMPARISON OF OBSERVED AND CALCULATED DRY DEPOSITION FLUXES ABOVE PINE FOREST

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Spatial and temporal variability of dry deposition of trace gases above different types of vegetation have been investigated in Hungary. Based on 5 field experiments (between 1991 and 1994) carried out over pine forest (Nyírjes, Mátra Mountains, Hungary), the turbulent fluxes and deposition velocities of ozone and sulfur-dioxide have been determined using the gradient method. With the results of this flux measurements the so-called inferential method was tested. In this method the fluxes can be expressed as a product of the gas concentration and the deposition velocity. This latter term can be calculated with a semi-empirical model in which this term is related to different resistances (aerodynamic, boundary layer, canopy resistance). The calculated and measured values of fluxes and deposition velocities were compared for the same time period. The probably explanations of differences and the possibility of application of inferential method above other vegetation types are also analyzed.

DOME TEMPERATURE AND DIRECT SOLAR INFRARED CORRECTION FOR UNSHADED PYRGEOMETERS

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Equipped with the standard dome temperature measurement pyrgeometers have to be shaded from direct sun. Shading the instrument avoids the inhomogenous heating of the dome. At remote stations, however, common shading systems are inadequate, because they need maintenance and do not work reliably under harsh climatic conditions. Therefore a newly installed radiation network in the Swiss Alps makes use of pyrgeometers with a fixed vertical shadowband. Only at solar noon a uniform shadow casts over the dome independent of the declination. Unshaded operation made it necessary to improve the standard dome temperature measurement. Extended experiments showed that 3 thermistors seperated by 120 degree at 45 degree elevation provide the best results to correct for the thermal emission of the dome in unshaded mode. A common shaded pyrgeometer is also protected from the unwanted inclusion of the infrared part of the direct sun in the measurement, that is part of the shortwave radiation measurement. The fixed shadowband demands a correction for this infrared part of the sun. On sunny days the amount of longwave direct solar irradiance transmitted to the sensor of the pyrgeometers can be easily determined by the solar noon information of the fixed shadowband. This amount depends on one hand on the cut-on of the pyrgeometer dome, which is inherent to the instrument. On the other hand the direct solar irradiance has a local and seasonal dependency (solar elevation, humidity). Detailed results of this correction method will be shown for different stations on different elevation and seasons. They prove the reliable operation of unshaded pyrgeometers. The neglection of this correction produces an error up to 10 W/m2, which can not be omitted if accurate surface flux measurements are needed; especially if a possible increase of atmospheric infrared radiation by a forced anthropogenic greenhouse effect shall be dedected.

FLUX MEASUREMENTS OF AMMONIA, ACIDIC GASES AND PARTICLES ABOVE A HEATHLAND

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Fluxes of NH_3, HCl, HNO_2, HNO_3, SO_2 and acidic particles (sulphate, nitrate, chloride and ammonium) were determined during nearly 4 weeks at the heathland Elspeetsche Veld, located in the centre of the Netherlands, using the gradient method. Concentrations were measured at two (three for NH_3) heights with continuous-flow denuders for the gases and a Steam Jet Aerosol Collector for the particles, both equipped with an Ion Chromatograph and a membrane-diffusion-conductivity system for on-line analysis of sampled extracts. Wind speed, wind direction, friction velocity, specific humidity, temperature, net and global radiation and sensible, latent and soil heat fluxes were measured as well. In addition, particle size distributions were continuously measured with an Aerodynamic Particle Sizer (0.5 - 15 μm) and a Scanning Mobility Particle Sizer (10 - 800 nm) and during some days 12-h average aerosol concentrations and size distributions (five classes) were determined with a Berner cascade impactor. The main aim of the campaign was to study the effects of both gas-to-particle conversion and aerosol dissociation, particularly of volatile ammonium nitrate and ammonium chloride, on the gradients and fluxes.

A SYSTEM FOR MEASURING FLUXES OF CO_2 AND WATER VAPOUR USING GRADIENT TECHNIQUES - FIRST RESULTS AND COMPARISON WITH EDDY-CORRELATION MEASUREMENTS

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Concentration differences of CO_2 and water vapour were measured above a mature spruce stand of 30m height in the Solling Mountains (Germany). In order to determine gradients of the trace gases in question the system was designed to directly measure their concentration differences with extreme accuracy.
Air is sampled at four levels and sent through four mixing tanks to get a hardware moving time average. The system uses two closed path LI-COR infrared gas analysers (LI-6262), one to determine the concentrations at 45m above ground and the other to simultaneously measure the concentration differences to one of three other levels (30m, 33m, 39m above ground). In this way a maximum of accuracy is achieved. To further minimise errors the LI-6262 is automatically calibrated every 24 hours.
To relate these measurements to the corresponding fluxes eddy-diffusities were calculated from profile measurements of windspeed and temperature taken at the site. Typical CO_2-gradients were about -0.05 ppm/m during the day and 0.01 ppm/m at night. The corrosponding fluxes were -8 $\mu mol/m^2s$ and 2 $\mu mol/m^2s$ respectivly. These results agreed well with eddy-corrolation measurements carried out simultaneously.

SEASONAL VARIABILITY OF THE CO_2 EMISSION AT A SPRUCE FOREST FLOOR: RESULTS OF CONTINUOUS EDDY CORRELATION AND SOIL SURFACE CHAMBER MEASUREMENTS

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Continuous long-term CO_2 flux measurements at a forest floor in a spruce forest (*Picea abies* [L.] Karst) in the Solling hills (Germany) were carried out: *i*) to study the daily and seasonal cycles of the CO_2 emission and its partitioning at the forest floor, *ii*) to estimate the contribution of the soil respiration in the total CO_2 flux above a spruce forest, *iii*) to compare the CO_2 fluxes measured by eddy correlation and by soil chamber methods, and *iv*) to parameterize the response of the soil respiration rate to changes of environmental conditions. CO_2 fluxes were measured by eddy correlation systems (a 3D-Ultra Sonic Anemometer-Thermometer (USAT-3) combined with a closed path infrared CO_2/H_2O analyser (LI-6262)) on a meteorological tower at two levels (39m and 09m) above and inside a forest canopy, and by a closed soil surface chamber with internal ventilation at a soil surface.
The results indicate a relatively good agreement between CO_2 fluxes measured by eddy correlation within the trunk space and by the soil surface chamber. Contribution of soil respiration in the total CO_2 flux above the forest did not exceed 2.5-3 μmol/m^{2}s over the summer and 0.5-1,5 μmol/m^{2}s during the early spring and late autumn and generally followed changes in soil temperatures. The soil water content during the measuring period was not a limiting factor for soil respiration.

THE KNMI HEXMAX STRESS DATA - A REVISIT

W.A.Oost (Royal Netherlands Meteorological Institute, de Bilt, the Netherlands)

Smith et al. (1992) discussed the wind stress measurements of the 1986 HEXMAX experiment off the Dutch coast, but left some uncertainty about the actual relationship between the stress and the wave field. In this paper we try to find a more definitive answer by looking at the mathematical consequences if we assume the Charnock coefficient to be either a constant or to have an inverse wave age dependence. It turns out that the constant coefficient does not produce coherent results, whereas the inverse wave age dependence does, provided the wave length is not too long. Furthermore an indication is found for an effect of the wave steepness on the stress.

A MEASURE OF INHOMOGENEITY OF THE LAND SURFACE AND PARAMETRIZATION PROBLEMS OF TURBULENT FLUXES IN NATURAL CONDITIONS

G.N.Panin, G.Tetzlaff, A.Raabe, H.-J.Schoenfeldt (Leipzig Institute of Meteorology, Germany).

Measurements of the surface turbulent fluxes (STF) of heat, moisture and momentum in the near-the-surface atmospheric layer by the eddy correlation method and their calculation, rely on the validity of the similarity theory of Monin-Obukhov, which requires stationarity and horizontal homogeneity. Experimental data taken at especially selected sites over land and particularly over sea surfaces allowed to develop this concept.

Recently performed experiments, purposely conducted in non-ideal conditions showed an underestimation of the STF values. Using such experimental data there was shown a corresspondence between turbulent fluxes underestimation and the terrain inhomogeneities. A method is developed for correction of underestimation of turbulent fluxes, a new parameter characterizing the inhomogeneity measure is introduced. Regarding this method should finally bring to the more adequate description of processes on the land surface with the help of mesoscale models and it might prove useful for the design of new validation experiments in non-ideal terrain.

Absolute Calibration of Longwave Radiation Instruments

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Longwave radiation instruments, like pyrgeometers, are usually calibrated using the Planck shaped response of black body radiation sources. Results from a recent Round Robin experiment show that calibration coefficients, determined in a number of significantly different black body calibration apparatuses, match consistently within about 1%. Nevertheless, the good agreement of the calibration coefficients for the individual instruments does not necessarily assure correct absolute measurements of the longwave downwelling radiation. Non uniform absorbtivity of the sensor and in particular the unhomogeneous spectral transmittance of pyrgeometer domes can produce a notable bias, when measuring a non Planck clear sky atmosphere with a black body calibrated instrument. The distinctive hemispherical distribution of the longwave radiation flux of a black body radiation source compared to the real sky, measured with a detector with non ideal cosine-law response, produces additional errors. To check the absolute value of pyrgeometer measurements a comparison is made with a windowless pyroelectric radiometer under clear night sky conditions. Sky radiance measurements at a solid angle of six degrees are made at four selected zenith angles. A Gaussian integration method is used to determine the hemispherical downwelling longwave irradiance on a horizontal surface. Pyroelectric detectors are fast, they have very high sensitivity and have an almost flat response up to 25 microns. An absolute cavity radiation source is used to calibrate the pyrolelectric detector. First results of this absolute calibration method will be presented and discussed.

SCINTILLATION CROSSWIND AND TURBULENCE MEASUREMENTS OVER COMPLEX TERRAIN

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M. Furger and W.K. Graber (Paul Scherrer Institute)

The measurement of atmospheric fluxes over complex terrain is problematic. Representativity and availability must be considered. Use of scintillometers has the advantage to yield integral, remotely sensed measurements of either turbulence parameters or crosswind speed over distances of up to several kilometres. Five scintillometers were used in the valley experiment of the project VOTALP (Vertical Ozone Transport into the Alps). Four instruments were set up across the Mesolcina valley at two different locations and at different heights. One scintillometer was placed along the valley axis in order to measure inside the slope wind zone. Measurements were made in August 1996 over 3 days during a fair weather episode.
As part of the project ECOMONT (Research on Mountain Ecosystems) five scintilometers were deployed in the region of Monte Bondone (IT) in September 1996.

FLOW DISTORTION BY SONIC ANEMOMETERS: COMPARISON OF THREE DIFFERENT TYPES OF SONICS

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Since April 1995 measurements of wind speed, temperature, CO_2 fluxes and water vapor have been carried out on a continuous basis above a 30m high spruce forest (d=22.7, z_0=2.5) in the Solling Mountains of central Germany. Wind speed and temperature are measured with a METEK 3D sonic anemometer (USAT-3) at a sampling rate of 10Hz. It is mounted on a 52m high meteorological tower at a height of 39m.
In order to examine flow distortions caused by the probe itself, two other sonics (USA-1, METEK and GILL, Solent 1012R2, Byral), each of them over a period of several weeks, were mounted at the same height close to the USAT-3. As these two probes have a geometric shape which is very different from that of the USAT-3, they are likely to cause less distortion of the wind flow, in particular to the wind flow in the vertical direction. In fact, the results of this comparison show that the values of the mean wind measured by the GILL and the USA-1 were up to 13% and 10% respectively, higher than those measured by the USAT-3. It was examined how the attenuation of the mean wind depends on the horizontal and vertical angle. A scheme has been developed to correct the fluxes measured by the USAT-3.

DETERMINATION OF RADIATION BALANCE COMPONENT AT THE SURFACE USING METEOSAT DATA

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Satellite images give opportunity to construct radiation map of better spatial resolution then those derived using only traditional surface measurement. A model calculating the component of radiation balance as global radiation, downward longwave radiation, longwave radiation balance and net radiation balance using satellite images has been developed in the Satellite Research Laboratory of Hungarian Meteorological Service to derive detailed deviation maps of Hungary. In the model the cloud parameters are determined from METEOSAT images moreover radiative transfer model and empirical formule are applied to estimate the surface fluxes. Daily amount of radiation balance components are approximated by statistical method from METEOSAT images received every 3 hours using traditional surface radiation data measured at radiation station Budapest in a 30 year period. In this study the method and a first results of the verification are presented.

SO_2-DEPOSITION INTO A SPRUCE STAND: LONG TERM MEASUREMENTS AND DEPOSITION PARAMETRISATIONS

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SO_2 dry deposition is still an important pathway for acidification of sensitive ecosystems. The dry deposition processes of SO_2 to rough surfaces like a forest canopy are not well developed yet for diurnal and seasonal changes.
For a period longer than one year the dry deposition flux of SO_2 to a 110 year old and spruce forest of 30m height in the Solling, middle germany, was monitored using an aerodynamic gradient method. The gradient of SO_2 was derived from five measuring levels above and in the stand by a tube system and two TE43 B/S analyzers.
In addition various micrometeorological parameters as PARadiation, humidity and temperature were measured continously to derive the deposition driving parameters.
The dry deposition velocity ranged between 0.2 and 2 cm/s varying with daytime and seasonal changes.
The stomata resistance ranged between 0 s/m and 100 s/m. The surface resistance ranged between 100 s/m and 650 s/m with a strong influence by humidity e.g. surface wetness.

Canopy Atmosphere Exchange

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A primary objective of various micrometeorological studies involving vegetation has been to better understand the process of gaseous exchange between the atmosphere and the biologically active canopy. This exchange influences the local weather as well as the climate. Therefore, a knowledge of the gaseous exchange at the canopy-atmosphere interface constitutes also a key aspect in our efforts to improve current climate models. In this paper, the Large-Eddy simulation model was used to simulate the gaseous exchange processes just above and within the canopy. The diffusion of gases from several source configurations within the canopy is modelled and comparisons with experimental data discussed.

EDDY CORRELATION FLUXES OF CO_2 ABOVE A MIXED FOREST CANOPY IN THE CAMPINE REGION IN BELGIUM

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As a part of the EUROFLUX (EU) project, a field experiment to measure fluxes of CO_2, latent and sensible heat above a mixed forest canopy in the northern part of Belgium is being conducted. The objectives are to 1). perform long term (over a period of 2-3 years) measurements of CO_2, latent and sensible heat fluxes and 2).to determine the sink strength of the forest ecosystem for atmospheric CO_2 and 3). to provide an objective database for models simulating forest growth and primary production. The eddy correlation technique, equipped with a three dimensional sonic anemometer and a fast response infrared gas analyser, is being employed to make flux measurements. The upper-storey vegetation consists mainly of *Pinus sylvestris* and *Quercus robur*, while the under-storey vegetation comprises of *Prunus serotina* and *Rhododendron ponticum*. We present in this paper the results on the CO_2 flux measured during 1996.

CO_2, LATENT AND SENSIBLE HEAT FLUXES ABOVE FOREST CANOPIES IN BELGIUM

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A thorough knowledge of the forest - atmosphere exchanges of CO_2 and water vapour is crucial to better understand forest growth and the role of forest ecosystems in the global carbon and water balance. Hence there is a need for quantification of surface fluxes from the forest canopies. Quantitative flux estimates along with responses of the various ecosystem processes to their respective controlling variables serve as valuable inputs to scaling models. Considering the heterogeneity evident in European forests, the EUROFLUX project aims to characterise carbon and water vapour exchange from a variety of forest types. With this view in mind, two forest sites were chosen in Belgium - one in Brasschaat in the Campine and the other near Vielsalm in the Ardennes region. *Pinus sylvestris* and *Quercus robur are* the major species at the Brasschaat site, while *Fagus sylvatica, Pseudotsuga menziesii* and *Picea abies* predominate at the Vielsalm site. The fluxes of CO_2, latent and sensible heat are being measured continuously above the canopies employing identical eddy correlation systems. The eddy correlation system at each site consists of a three dimensional sonic anemometer and a fast response infrared gas analyser. Here we compare the results on the CO_2 and water vapour exchange from the two forest sites during 1996.

AN EXPERIMENTAL STUDY OF SURFACE TRACE GAS FLUXES IN THE COMPLEX TERRAIN OF SWITZERLAND AND THEIR CORRELATION TO VERTICAL CONCENTRATION AND FLUX PROFILES IN THE PLANETARY BOUNDARY LAYER

F. Siegrist & W. Eugster (Institute of Geography, University of Berne, Department for Climatology and Meteorology, Hallerstr. 12, CH-3012 Berne, Switzerland)

In complex terrain removal and emission of trace gases at the soil-vegetation-atmosphere interface influence the concentration profiles in the atmosphere above the surface in a different way than over flat and homogeneous surfaces. It is aimed to investigate how vertical concentration gradients in the planetary boundary layer and the associated flux divergence relate to surface fluxes measured by micrometeorological techniques.
The experimental concept assesses the volume flux budget of the air volume between the complex surface topography and the top of the planetary boundary layer over the Swiss Plateau. Eddy correlation flux measurements at the surface are combined with tethered balloon profile soundings using the continuity equation for scalars in the atmosphere.
Results from the first intensive measuring campaign during the Swiss BAT project (= Regional Budgets of Atmospheric Trace Gases) in summer 1996 are presented. The region chosen for these measurements is the 'Seeland', the largest flat rural area on the Swiss Plateau, which has a complex landuse structure. Future BAT campaigns are scheduled for 1997 and 1998.

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MICROMETEOROLOGICAL INVESTIGATIONS OF TRACE GAS FLUXES AT THE SOIL-VEGETATION-ATMOSPHERE INTERFACE

F. Siegrist (Geographical Institute, University of Berne, Departement for Climatology and Meteorology, Hallerstr. 12, CH-3012 Berne, Switzerland)

BAT is a project focussing on the dynamic exchange processes of nitrogenous and other trace gases at the soil-vegetation-atmosphere interface in rural areas. The first intensive measuring campaign was held in summer 1996 in the Swiss Seeland region, the largest flat rural area on the Swiss Plateau, more campaigns are planned for 1997 and 1998. The chosen site consists of an interesting inhomogenity as far as landuse is concerned. As inhomogenous terrain is typical for Switzerland, it is an important aim of the project to find reliable investigation methods for measuring fluxes under such conditions. The presented poster treats the following issues: improvement of eddy correlation measurements of micrometeorological and trace gas fluxes; combination of near surface flux measurements and vertical tethered balloon profile soundings using the theoretical approach of the ground based thermodinamic energy equation method; vertical flux divergences of trace gas fluxes above inhomogenous terrain.

THE MODEL OF MESOSCALE METEOROLOGICAL REGIME FOR THE FOREST AREA

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G. Gravenhorst (Institute of Bioclimatology, Georg-August University, Büsgenweg 2, 37077 Göttinget, Germany).

The specialised model for energy and mass exchange in horisontally heterogenious vegetation canopy and in atmospheric boundary layer above it is presented. This model based on the well-known hydrothermodynamic equations and justified parametrisations is able to adequately reproduce the main regularities of turbulent flow. Also the solar radiation, heat and water vapour transfer submodels are included in mesoscale model. The developed model has been tested with several numeric experiments as applied to one, two and three dimensional cases of turbulent flow in the atmospheric layer above the surface of forest area. The model describes the horizontal distribution of vertical velosity and turbulent energy over the forest in Solling region (Germany) rather realistic. The numerical experiments show the increasing of turbulent energy near the borders of the various vegetation in Solling region also very realistic.

PROBING THE SURFACE STABLE BOUNDARY LAYER

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L. Conangla, E. Ferreres and J. Vilà (Dpt. Fisica Aplicada, Universitat Poli tecnica de Catalunya, 08028 Barcelona, Spain)

Surface mean and turbulent measurements were taken under strong stable conditions at Tarragona (Spain) during five days. These observations were complemented with wind and temperature vertical profiles collected by means of a threemonoestatic acoustic sounder and a tethere d balloon. In order to detect the presence of gravity waves, three microbarographs were located at the experimental site, in the stable layer under study. Although the final data set consists of few points, general agreement is found with similarity theory. The spectral analysis showed a well defined inertial subrange.

TURBULENT EXCHANGE ABOVE DIFFERENT CANOPIES

M.R. Soler, P. Buenestado (Dpt. Astronomia i Meteorologia, Universitat de Barcelona, Avda. Diagonal 647, 08028 Barcelona, Spain)
L. Conangla. E. Ferreres (Dpt. Fisica Aplicada, Universitat Politecnica de Catalunya, 08028 Barcelona, Spain)

The aim of this work is to study the turbulent exchange between the atmosphere and the underlying surface. We have considered three types of surfaces, irrigated agricultural area, dry cereal agricultural area and non agricultural dry area. The values of the surface turbulent fluxes based on Bowen ratio-energy balance and similarity theory of Monin Obukhov methods are calculated continuously since October 1996. In determined conditions these values are compared with those obtained by the eddy correlation system. The results obtained allow us to compare the agreement between calculated and measured fluxes by different methods, to investigate the effect of the location and type of surface and the influence of meso and synoptic scales on the surface fluxes.

Long-term measurements of the turbulent vertical ozone flux onto a field of barley

D. Sprung, H. Güsten, and G. Heinrich (Institut für Meteorologie und Klimaforschung, Forschungszentrum Karlsruhe/Universität Karlsruhe, D-76021 Karlsruhe, Federal Republic of Germany)

A robust and light-weight ozone sensor was used successfully in continuous measurement of the eddy flux over a barley field from April until August and over the same flat harvested field from the beginning of August until the end of September 1992. The measuring site near Bellheim (49°10'33"N, 8°16'35"E) in south west Germany is located on a flat agricultural terrain (elevation 130 m) of approximatley 3 x 4 km^2 in the Upper Rhine Valley providing a considerable homogeneous fetch of more than one kilometer upwind of the measuring tower. A total of 2658 half-hourly mean values of the turbulent ozone flux were obtained continuously throughout the half year using the eddy correlation technique. A statistical evaluation of the ozone fluxes divided into weakly mean periods provided the following information:

- The maximum weekly ozone fluxes onto barley vary by a factor of 3 (23 - 69 ppbv cm s^{-1}). The lowest and the highest weekly maximum values of the ozone fluxes were measured in two consecutive weeks in July which indicates the strong influence of the weather on the ozone deposition flux,
- the weekly mean deposition velocities of ozone over the entire measurement period vary from 0.16 to 0.35 cm s^{-1},
- the largest values of the mean weekly ozone fluxes over the entire measurement campaign were obtained in June during the period of strong increase in plant growth (30 to 85 cm) as well as that of the leaf area index (1.5 to 7).

RESISTANCES TO OZONE DEPOSITION TO AN ARCTIC AAPA MIRE

J.-P. Tuovinen, **M. Aurela** and T. Laurila (Finnish Meteorological Institute, Air Quality Research, Sahaajankatu 20 E, FIN-00810 Helsinki, Finland; juha-pekka.tuovinen@fmi.fi)

Ozone deposition and related turbulent fluxes were measured by the eddy covariance method on an open flark fen in Northern Finland (69°08'N, 27°17'E), 200 km north of the Arctic Circle. The campaign period (15 Aug. to 13 Sept. 1995) extended to the decline of the growing season. The fen comprises patches of open water, hummocks covered by mosses and shrubs, and wet sedge-vegetated hollows, as typical for the northern aapa mire zone. Low deposition velocities of ca. 0.2 cm s^{-1} with a weak diurnal variation were measured for ozone. The fluxes were interpreted in terms of a common big-leaf resistance model. When a molecular resistance parametrisation derived for vegetated surfaces was applied, the residual bulk surface resistance exhibited an apparent dependency on the flow. This was taken as an indication of bluff-body nature of the hummock-hollow surface, which adds to the uncertainties in determining the surface resistance. The non-stomatal pathways seemed to dominate the surface resistance, and no correspondence with the damping of the stomatal exchange was observed.

A RELAXED EDDY ACCUMULATION SYSTEM FOR VOLATILE ORGANIC COMPOUNDS

R. Valentini, (Dep. of Forest Environment and Resources, University of Tuscia, I-01100 Viterbo, Italy), P. Ciccioli (CNR - Institute for Atmospheric Pollution, Montelibretti, Italy), G. Seufert (JRC, European Commission, Ispra, Italy).

A system for measuring Volatile Organic Compounds (VOCs) emitted by vegetation canopies has been developed. The system here presented is constituted by traps of adsorbant material (Carbon or Tenax) placed at the inlet of the two sampling lines, thus avoiding potential problems of time lag calculations and contamination of the reservoirs.

A software was developed for on-line calculation of the semi - empirical coefficient for the application of the relaxed tehory, based on the temperature time series and the sensible heat eddy flux measurements. Theorethical considerations on the methodology and the parctical applications are presented.

TOWARDS A TRACEABLE MEASUREMENT OF NET RADIATION

R.Vogt, Chr. Feigenwinter, E. Parlow (MCR Lab, Department of Geography, University of Basel, Spalenring 145, CH-4055 Basel)

In surface energy balance studies there often appears a closure gap: the measured turbulent fluxes of sensible and latent heat do not sum up to the available energy, consisting of net radiation and storage fluxes. This presentation discusses the contribution of the measurement of net radiation to the energy balance closure problem, especially in the light of a lacking standard for calibration. Results are reported from two experiments, where three types of net radiometers (6 Schulze-D=E4ke, 40 Schenk Mod. 8111, 1= REBS Q7.1) are compared to a new reference consisting of a combination of two pyrgeometers (Eppley PIR) and two pyranometers (CM21, CM11). The instruments (except CM11) were calibrated at the World Radiation Center, Davos, where also the dome temperature measurement of the pyrgeometer was modified. Using the factory calibration for the Schenk pyrradiometers, the differences ranged between -8 and +20 %. During night time the magnitude of net radiation was underestimated up to 30 %. The adjustment to the reference measurement can be done within =B15% or =B115Wm-2, whichever is largest. The assessment of the closeness of the measured net radiation to the true value is still a difficult task, but it can be stated, that the large closure gaps in the range of 20 to 50 % of the available energy, as reported in many studies, are in general not due to uncertainties in measured net radiation.

ON THE VARIATION OF THE ENERGY-BALANCE COMPONENTS IN THE REKLIP AREA

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Within the framework of REKLIP (Regio-Klima-Projekt) performed in the Upper Rhine Valley and the surrounding mountains 36 meteorological stations were installed at different altitudes, in order to investigate the climatic state and the energy balance with high temporal and spatial resolutions.The main results are: (i) an evaporation increase in the Rhine Valley between northerly stations and southerly stations was found, although there is only a small difference in altitude between the stations. The increase can be related to the increase in precipitation. Nearly a constant ratio of 0.8 between the evaporation and the precipitation is given. The higher precipitation can be related to a remote effect of the orography, because the southerly stations are situated in the luff of higher mountains. (ii) the increase in the sensible and the decrease of the latent heat fluxes with the altitude at the slope of the Black Forest, although there is a strong increase in precipitation from the Rhine Valley (880 mm y^{-1}) to the Black Forest (1340 mm y^{-1}). Explanation for this behaviour can be given from the relation of the temperature gradient to the moisture gradient. In order to receive the energy balance for the REKLIP area with higher spatial resolution instead of point measurements, a set of equations was derived. It can be proved that these equations reproduce the measured behaviour of the energy balance in the REKLIP area.

TURBULENT FLUXES ABOVE A SPRUCE CONOPY

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Annual variation of turbulent fluxes (momentum, latent and sensible heat, ozone) above a spruce canopy are presented. The gradients of the important variables are measured at a tower in 5 levels above then canopy (28 m height) with a frequency of 0.1 Hz. Eddy - correlation system run with a measurement frequency of 10 Hz at the same site in 41 m above the ground. It indicates that the turbulent fluxes are highly determined by the right choose of the time intervall. Therefore the convergence of the fluxes must be tested. Applying the Monin - Obuchov theory, the convergence of the calculated fluxes must also be analysed. The ozone fluxes must be corrected because of chemical reactions. The results for different time intervalls are compared with fluxes derived from constant time intervalls of 1/2 hour and with fluxes derived from the Bowen ratio.

Convener: Hojstrup, J.
Co-Conveners: Corsmeier, U.; Seibert, P.

A MODEL FOR THE BOUNDARY LAYER CLOUDS USING SECOND ORDER TURBULENCE CLOSURE

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We present a second order turbulence model for the planetary boundary layer(PBL) which is extended for application of a statistical scheme of the subgrid-scale condensation. The model contains a prognostic equation for the turbulent kinetic energy. The other second order moments modelled through the parameterization of the third order moments which are obtained through a convective mass-flux argument. For the heat flux this leads to a formulation with the usual down-gradient term and a counter-gradient term. The effect of the turbulence scheme on the partial cloudiness scheme will be discussed and the performance of the model is tested by considering different cloudy PBL conditions and comparing the results with observed reference cases. The model produces the mean as well as the turbulent quantities that are in a reasonable agreement with the observational data.

EXPERIMENTAL METHOD OF ACOUSTIC TOMOGRAPHIC MONITORING OF THE ATMOSPHERIC SURFACE LAYER

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Acoustic tomography is proposed as a method for remote monitoring of atmospheric variables. An experimental method is presented which provides volume averaged values of meteorological parameters.
In such a system, a number of sources transmit at the same time an acoustical signal which are detected at a number of receivers. The sources and receivers were positioned at an array of 100×200 m. By monitoring the travel time of an sine wave (500 Hz) between each possible source-receiver pair a volume is spanned by a number of acoustic paths. The distances between the speakers and microphones were determined with a very high precision so that the measured travel time gives the sound speed as an answer.
Travel time measurements were inverted to obtain estimates of the relevant meteorological parameters.
Improvements over traditional in situ methods are e.g. that the sensors need not be located at the field point being measured and more data points per sensor can be generated than by traditional techniques.
Experimental estimated values for meteorological parameters such as temperature and wind velocity in different levels are used for the validation of the tomographic models .

VERTICAL TRANSPORT PROCESSES IN THE ATMOSPHERIC BOUNDARY LAYER

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In 1994 the field campaign SADE94 (SANA deposition experiment) was conducted in the five new federal states of Germany to study among others the vertical mixing of air pollutants in the convective planetary boundary layer (PBL) over a homogeneous surface near the small saxon village Melpitz. Using a radiosounding system, a tethered ballon and a sodar system, the temporal development of the PBL was analysed at October 11, 1994. Airborne measurements of meteorological parameters and chemical spezies like SO_2, NO, NO_2 and O_3 were made twice a day, in the early and late afternoon, by the research aircraft DO 228 of DLR, operating along eight horizontal flight legs between 150 m agl and 1000 m agl above the ground station. Organized updrafts of about 800 m diameter, polluted with NO_x, and compensating downward motion were detected in the upper PBL. A wavy structure of polluted air originating from the PBL and clean air from the capping inversion was found at the interface between PBL and capping inversion.

MODIFICATION OF FLOW OVER COMPLEX TERRAIN BY CHANNELLING AND LEE-EFFECTS

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In the 1992 field campaign REKLIP (three nation REGIO-KLIMA-PROJEKT of Germany, France and Switzerland) the influence of complex terrain on the flow within the boundary layer was investigated in the Rhine Valley during a high pressure situation in winter with northeasterly flow. In the valley, surrounded by the Black Forest and the Vosges mountains, often secondary circulation systems appear, driven either by thermal effects or by dynamic effects caused by flow over or around mountain ridges. Observations are presented with special emphasis on the concurrence of different secondary flow systems across the valley near Strasbourg. Channelling causes a turning of the wind direction from NE above the valley to NNE in the northern part of the Rhine valley. But in the lee of the mountain Hornisginde (1163 m), at the eastside of the valley the wind in the lower 400 m above ground blew from SSW, 180 degree opposite to the flow in the western part of the valley. Beside the stable stratification and the surface pressure gradient in the valley the phenomenon is caused by flowsplitting around the Hornisgrinde due to low Froude numbers. It is shown, that the flow over the mountain causes a wavy structure in the inversion layer downstream at the leeside, while flow around the mountain is responsible for the reverse flow at the valley bottom.

ON A ROLE OF REMOTE SENSING AND SYNOPTIC ANALYSIS IN THE ABL MIXING MECHANISMS STUDY AND MODELING

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Study of the atmospheric boundary layer (ABL) behaviour is two-folded problem. Its first side is dictated by current needs that ensue from the modelling possibilities. The second one is connected with physics of the ABL itself. Better understanding of main mixing processes in it may not immediately lead to new practical results, but in future it will result in improved models. The remote sensing technique (especially sodar and lidar) gives besides quantity data the unique possibility to visualise the structural nature of the ABL and reveal the great diversity of shapes and space-time distributions of long-living organised structures. Analysis of the vast remote sensing data, combined with analysis of synoptic and orographic factors is carried out. Description, classification and an attempt of physical explanation of the typical structures and their evolution are made. Statistical data on frequency of different types of the structures under different seasons, synoptic conditions, terrain type and bed surfaces are presented. Some discrepancies between observed ABL structure and widespread ABL models are demonstrated.

OROGRAPHICALLY INDUCED SECONDARY CIRCULATIONS IN THE AREA OF FREIBURG-SCHAUINSLAND

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Complex terrain structure often leads to the development of secondary circulation systems. Additionlly, the mixed layer depth shows a strong spatial variation. Both, the secondary circulations and the varying mixed layer depth lead to horizontal transport and vertical diffusion of air pollutants which are different from those over homogeneous terrain. The area of Freiburg-Schauinsland has such a complex terrain structure with mesoscale mountains and valleys. In summer 1996 an experiment was performed to study the evolution of secondary circulation systems and boundary layer heights. Therefore, several surface stations, two tethersonde stations, one radiosonde station and two sodar systems were installed. In order to analyse the influence of the meteorological conditions on the concentrations the surface stations were equipped to measure O_3, NO and NO_2,. It was found that in the Kirchzartener Valley - even under convective conditions - a mixed layer height of only a few hundred meters established. This low mixed layer was caused by the change from mountain to valley winds and the accompanied cold air advection from the Rhine Valley into the Kirchzartener Valley. The low mixed layer height reduces vertical mixing significantly. The onset of the valley wind also is accompanied by an increase of air pollutants transported from the highly industrial areas of the Rhine Valley to the mountain sites.

CLOSURE OF LOCAL TURBULENT TRANSFER MODELS FOR ATMOSPHERE USING OPERATIVE MEASUREMENTS DATA

V.Kramar (Inst. of Atmospheric Phys. of RAS, Pyzhevski per.3, Moscow, Russia)

(1) To solve the above problem connected with models of local area transport of pollutants, nowcasting and very short range forecasting of pollutants distribution in the atmospheric boundary layer (ABL) it was proposed to use data of uninterrupted measurements of the ABL parameters by sound locator (sodar). The information obtained with the sodar data analysis describing vertical distributions of parameters of current state of ABL and its history in the point of a unit location may be used in the models instead of mean values of the "empirical constants" and pre-calculated vertical distributions. Conditions and limits of the method applicability are discussed. (2) Simple semi-empirical model of turbulent transfer in terms of turbulence kinetic energy, eddy viscosity, turbulence scale was selected to show the method potentials. The model degenerates for the lower layers. That gives the possibility to determine from the sodar data values of some model constants valid for the whole ABL. Then vertical distributions of turbulence parameters were calculated using sodar data vertical profiles. (3) These characteristics of the ABL obtained in the ARAL-92 expedition were used as the empirical material. The material is: instantaneous profiles stored continuously by a 3-component doppler monostatic sodar representing values of three components of wind velocity and Ct2 parameter up to the heights of about 300m. The experiment was carried out on the dry bed of the Aral Sea in the moving sand zone in conditions of high horizontal uniformity and low roughness. Some episodes of dust storms were registered. (4) The vertical distributions calculated are presented.

NON-ISOTROPIC TURBULENCE IN THE MARINE ATMOSPHERIC BOUNDARY LAYER DURING THE SEMAPHORE EXPERIMENT.

D. Lambert, P. Durand, B. Bénech and A. Druilhet (LABORATOIRE D'AEROLOGIE UMR CNRS/UPS 5560)

The SEMAPHORE experiment was conducted in the Azores region during fall 1993. Several survey missions were carried out by two French aircraft, instrumented to measure "in situ" the turbulence structure of the Marine Atmospheric Boundary Layer (MABL) in the open ocean. The flights plans included several 30 to 200km long horizontal legs, along and across the mean wind direction at different altitudes. The statistical analysis of the collected data clearly demonstrates the anisotropy of the horizontal structure of the turbulence intensity, featuring an elongated shape in the direction of the mean wind. The values of turbulence moments depend on the sampling direction and fluxes along the wind direction can be underestimated by 20 to 30 % .

DIURNAL EVOLUTION OF COHERENT STRUCTURES IN THE PLANETARY BOUNDARY LAYER (TRAC EXPERIMENT)

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The Planetary Boundary Layer (PBL) has been considered for a long time as made of homogeneous and isotropic turbulence. This hypothesis allows to use a statistical method which has conducted to a turbulent parameterization used in numerical models. This approach does not take into account coherent structures such as cells and horizontal rolls vortices. These organizations of the convection in the PBL feed the turbulent motion and at a larger scale participate in the vertical exchanges and so modify the energy budget. The study of the coherent structures and their role in the energy transfer in the PBL was the scientific goal of the TRAC experiment (Turbulence-Radar-Aircraft-Cells), conducted in France in june 1993 over a homogeneous and flat area during anticyclonic situations. Two complementary measurements were used, in situ measurements with an instrumented aircraft and the 3-dimensional view of a C-band Doppler radar. A method based on the two-dimensional autocorrelation of the horizontal reflectivity planes brings out the main mode of the coherent structures which appeared every day during the experiment. These organizations, evolving during the day between cells and rolls, were related to the dynamics and thermodynamics characteristics of both PBL and free atmosphere which can affect the PBL through the cloudy layer.

PARAMETERIZATION OF CLOUD AT LOCAL SCALE

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Research has been conducted in Logan, Utah, U.S.A., since October 1995 to measure radiative fluxes, temperature and moisture near the ground to parameterize clouds at local scale in this semi-arid mountainous valley. We are using two Kipp & Zonen CM11 pyranometers (one inverted) to measure the incoming and outgoing solar (shortwave) radiation, respectively; and two Kipp & Zonen CG1 pyrgeometrs (one inverted) to measure the incoming (atmospheric) and outgoing (terrestrial) longwave radiation, respectively. These instruments are equipped with Kipp & Zonen CVB1 blowers powered by CVP1 units (if necessary) to prevent precipitation of dew and frost which otherwise would disturb the measurement. Wind speed and direction, and precipitation are also measured. All these parameters are measured every 5 seconds and averaged into 20 minutes intervals during all weather conditions and stored in a data logger.

The preliminary results indicate that the atmospheric radiation measured by pyrgeometer during cloudless skies was almost identical with the one computed by Brutsaert's formula (using the 2 m air temperature and moisture). During cloudy skies, the incoming longwave radiation measured by pyrgeometer is greater than (depending on the cloud type and degree of cloudiness) that computed for the cloudless skies. The additional longwave radiation during the cloudy skies comes from clouds in the waveband which the gaseous emission lacks, e.g. from 8-13 μm (the so-called atmospheric window). Based upon the surface thermodynamic conditions we have parameterized clouds (cloud base temperature, cloud base height, and cloud coverage) at local scale.

ON THE SENSITIVITY OF FLUXES TO TYPE A AND TYPE B LAND SURFACE COVER

Nicole Mölders (LIM - Institut für Meteorologie, Universität Leipzig, Stephanstraße 3, D-04103 Leipzig, Germany)

The atmospheric response to type A and B land surface cover in the hierarchy of Shuttleworth (1991; Surv. Geophys. 3-30) is investigated by comparing results provided by a meso-β-scale meteorological model with and without consideration of subgrid-scale heterogeneity by an explicit subgrid scheme. In the simulation without the explicit subgrid scheme the dominat landuse type within a grid cell is used to calculate the water and energy fluxes, for which the patches of homogeneous landuse extend several grid cells and can be regarded as a type B land surface cover. The landscape represented on the explicit subgrid corresponds to a type A land surface cover. Six degrees of subgrid-scale heterogeneity with respect to the landuse are distinguished. The obtained changes in cloud structures, precipitation pattern and intensity, evapotranspiration and soil wetness were closely related to the degree of subgrid-scale heterogeneity. Physical heterogeneity within a grid cell, i.e., that of the surface temperatures and soil wetness, which results from the subgrid-scale heterogeneity, enhance the differences, especially, if precipitation occurs. The local recycling of water decreases with increasing degree of subgrid-scale heterogeneity. Consequently, broken cloud fields and a shower-like precipitation form for heterogeneous areas. Hence, the physical patchiness of surface quantities going along with a higher degree of heterogeneity seems to contribute to the persistence and the enhancement of the physical heterogeneity. On the contrary, the type B land surface cover tends to continuously provide water to the atmosphere yielding to a stratiform cloud and precipitation distribution and less physical heterogeneity.

1D-MODELLING OF ATMOSPHERIC VERTICAL EXCHANGE PROPERTIES WITHIN AND ABOVE A SPRUCE FOREST WITH TRANSILIENT TURBULENCE THEORY

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To quantitatively describe deposition- and emission rates of atmospheric trace gases for forest ecosystems and soils by profile measurements it is necessary to model the turbulent exchange properties of the atmospheric boundary layer above and within the forest canopy.
This report explores the turbulent exchange between layers within and above a forest by means of the transilient turbulence approach. The numerical model is based on the boundary layer model structure and the parameterisations of energy transfer processes at the phytoelements (MIX et al. 1995) and is using the transilient turbulence approach extended to forest canopies (Inclán, 1996). The biometric properties of the spruce stand at Solling Mountains and the measured profiles of temperature, specific humidity and horizontal wind speed are parameters to derive a transilient matrix for this site. Simulated vertical fluxes of H_2O, heat and momentum are compared with eddy correlation measurements. Measured counter gradient vertical fluxes within the trunk space are reproduced by transilient approach. Furthermore the transilient exchange matrix is discussed as a tool for deriving statistical properties of the turbulent exchange within and above a tall forest stand.

THE USE OF KITES TO STUDY THE ANTARCTIC BOUNDARY LAYER.

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A system for profiling meteorological variables in the Antarctic is described. Kites are employed as a method of raising and lowering measuring equipment. Two separate experiments are examined. The first involves installing a static site at the British Antarctic Survey's Halley Research Station capable of allowing year round profiling up to 1000 m. With this system regular, high resolution monitoring of the Antarctic stable boundary layer is possible as well as other studies such as calibrating the radiosonde ascent data taken daily at the station and also calibrating data from a SODAR which is soon to be installed at the station.
The second involves profiling at remote site on the continental slope margin in Coats Land south-east of Halley with a lightweight, highly portable profiling system capable of taking measurements up to 500 m. Investigation here is of the mesoscale drainage and katabatic flow evolution occuring along the continental/shelf ice interface.These measurements will be combined with data from a transect of AWSs ascending the Coats Land continental slope as part of CLAMP (Coats Land Mesoscale Project).

NUMERICAL MODEL OF ACOUSTIC TOMOGRAPHY INSIDE THE ATMOSPHERIC SURFACE LAYER

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Theoretical estimations will be presented which direct provide volume averaged values of meteorological parameters (air temperature) by means of acoustic remote sensing and so deliver rather consistent data for validation of numerical atmospheric models.
The procedures use horizontal propagation of acoustic waves in the atmospheric surface layer. From measurements of acoustic parameters (travel time in our case) with transmitters and receivers on different places in an array of 100×200 m over grassland the state of the crossed atmosphere can be estimated. Derivation of volume averaged values results from invertation of single values of the selected acoustic parameter (acoustic tomography). An increased number of sources and receivers improve resolution of the measuring field.
For the development of experimental methods the demanded resolution for measurements of travel time is very important in order to determine volume averaged values for meteorological parameters with sufficient accuracy (temperature: 0.2 K). Sound propagation in a turbulent atmosphere can be studied by coupling atmospheric models with ray-tracing models. The simulated acoustic parameter values will be compared with experimental values for sound propagation and thereby measurement errors and the influence of atmosphere and soil conditions can be calculated.

A COMPARISON OF PRACTICAL METHODS FOR THE DETERMINATION OF MIXING HEIGHTS

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As a part of the COST Action 710 (Harmonization of meteorological preprocessors for dispersion modelling), different practical methods for the determination of mixing heights have been compared on the basis of data sets from operational sites (Cabauw/NL, Payerne/CH) and field campaigns (SANA/SADE, D). The comparison includes evaluations of measurements by radiosondes (parcel and Richardson number methods) and sodars as well as modules of operational preprocessors (OML, HPDM, RODOS, FMI, Servizi Territori), based on surface layer scaling for the stable and near-neutral ABL and on the integration of slab models for the convective boundary layer (CBL). All the preprocessors had certain difficulties; if suitable measurements are available, the mixing height should be determined with a parcel method under unstable and a Ri number method under stable conditions, but there are still unsolved questions. Further findings concerning the application and future development of empirical methods and preprocessors will be presented.

Sodar and surface Layer measurements along the The reeves
glacier air flow path in antarctica

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Abstract
Two measurements station have been set up in the area of
Terranova Bay in summer 1994-95 to study the evolution o
f the boundary layer during the transition between the wi
nter and the summer circulation. They have been located o
n the Reeves Neveé (at 1200 m ASL) and on the Nansen Ice
Sheet at the confluence of the Reeves Glacier. Both site
s were equipped with a triaxial Doppler sodar, and with
fast response meteorological sensors. An attempt to rel
ate the depht of the gravity current estimated from sodar
data at the Reeves glacier with the katabatic flow observ
ed in both sites is presented. The intercomparison betwe
en sonic anemometers and sodars data is presented to det
ermine the reliability of different sensors to describe a
nd interpret the atmospheric circulation with particular
attention to the katabatic flow events. The momentum flu
xes obtained from the sodar data have been compared with
those measured with sonic anemometers.

OA13 Atmospheric convection

Convener: Hantel, M.
Co-Conveners: Redelsperger, J.-L.; Schaller, E.H.; Steinacker, R.

HOW IMPORTANT IS THE CONTRIBUTION OF THE MESOSCALE CONVECTIVE COMPLEXES TO THE SAHELIAN RAINFALL ?

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The Sahelian rainfall is mostly of convective origin, 95% of the annual rainfall being produced by Mesoscale Convective Systems. Combining satellite and ground based data, a subset of long-lived and well organised systems has been identified. They present the general characteristics of the Mesoscale Convective Complexes (MCC's), as originally depicted by Maddox in 1980. The tracking of convective cloud clusters from METEOSAT IR data over West Africa during the 1993 rainy season shows that these MCC's are preferentially located over the Sahel and that they are responsible of 80% of the convective cloud cover. The associated rainfall was investigated in deep details using the dense EPSAT-Niger recording raingauge network covering a 16,000 km^2 area in the surroundings of Niamey (13.5°N ; 2.5°E). Between 1990 and 1995 the MCC's have accounted for 75% of the annual rainfall over the study area. The interannual variability is mostly linked to the number of MCC's recorded during the rainy season. The average rain yield associated to each MCC is about 17 mm and varies little. The rainy season may be divided into two sub-periods : the core (July- August) and the margins (May- June and September-October). The proportion and average yield of the MCC's are larger during the core. The average yield of the other convective systems remains constant around 5 mm during the whole rainy season.

DOPPLER RETRIEVAL OF KINEMATIC ENERGY DISSIPATION RATES AND APPLICATION IN NOWCAST MODELS OF THUNDERSTORM DEVELOPMENT

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C.E. Pierce and P.J.Hardaker

Although Doppler processing capabilities are becoming standard on modern weather radar systems, operational use in Europe is often limited to enhanced clutter suppression, or at best, limited retrieval of wind field information. Perhaps surprisingly, measurements of spectral broadening have received comparatively little attention, despite the fact that this parameter may be inherently more suited to network compositing and integration with other meteorological information in forecast models. One problem is undoubtedly the difficulty of interpreting spectral broadening in a meteorological context and this paper will attempt to identify both the problems involved, and some of the potential areas of application.
Spectral width measurements from an operational Doppler radar will be used to derive estimates of Eddy Dissipation rate and an attempt will be made to quantify the problems, both meteorological and non-meteorological, associated with this operation. As with other radar parameters, this information is likely to be most beneficial in nowcast models with high spatial and temporal resolutions. This will be illustrated with reference to the GANDOLF system, which is based around an object-oriented model of thunderstorm development and is currently undergoing operational trials at the Met. Office.

RADIATION BUDGET COMPONENTS AT SURFACE AND AT TOP OF ATMOSPHERE FOR CONVECTIVE CLOUDS

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For a few selected cases between 1990 and 1996 radiation budget components at surface were inferred using NOAA-AVHRR and Meteosat data with respect to convective cloud situations. The investigated areas are the watershed of the Baltic Sea and Central Europe.
To calculate the radiation budget components at surface (SFC) and at top of atmosphere (TOA) from remotely sensed data, a complex analysis scheme could be applied. This scheme contains: a narrow to broadband conversion for TOA fluxes, a detailled cloud classification to define the microphysical cloud properties, a snow/sunglint threshold technique, a landuse classification for clearsky conditons, a determination of cloud optical properties, and finally the determination of surface radiation budget components. The last two modules are based on an inverse technique, which uses a two-stream approximation for radiative transfer and additional informations from synoptical data, especially parameters to describe cloudfree atmospheric conditions (relative humidity and horizontal visibility for the aerosol content.) Thus, time series (sequences of two days with an hourly resolution) of cloud cover and radiation fluxes (SFC and TOA) will be presented.

THE PARAMETERIZATION OF DEEP CONVECTION: MASS FLUX REPRESENTATIONS AND SOME EXTENSIONS TO THE BETTS-MILLER SCHEME

Alan K. Betts (Atmospheric Research, R.D. 3, Box 3125,Pittsford, VT 05763, USA)

Insights into the parameterization of tropical convection from two decades of diagnostic studies are reviewed. The life cycle of a convective mesosystem mass flux is described using day 245 from the GARP Atlantic Tropical Experiment as example. The thermodynamic differences between non-precipitation convection and precipitating convection are discussed, as well as the importance of the mid-tropospheric freezing level and the saturation pressure budget in the tropics. The strengths and weaknesses of the mass flux representation of deep convection is discussed. The three key vertical modes in the convective heating and drying structure, which have been identified by diagnostic studies are outlined. Two are related deep modes associated with precipitation and deep tropospheric ascent, but a variable upward equivalent potential temperature (E) flux. The other is the double mode structure with ascent in the upper troposphere over descent in the lower troposphere, coupled to inflow at the freezing level, with no net precipitation or transport of E; the mode associated with deep mesoscale anvils. We suggest two extensions to the Betts-Miller parameterization. One is a formulation of the adjustment time in terms of grid-scale and gravity-wave propagation speed for the two primary modes. The second is an explicit parameterization of the mesoscale anvil "couplet mode".

ATMOSPHERIC CONVECTION:SOME BASIC CONCEPTS

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This review will address the characteristics of different types of convection in the atmosphere from dry and non-precipitating boundary layer convection to deep convection and organized mesosystems; as well as the interaction of convection with the surface and the large-scale flow. I will try to assess our present understanding, and what issues remain unresolved or poorly modeled.

CONTRIBUTION OF A MESO-SCALE ANALYSIS TO CONVECTION NOWCASTING

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We study the contribution of surface data to convection nowcasting outside mountainous areas and under weak synoptic forcing. The CANARI optimal interpolation mesoscale analysis scheme is used, which combines guess-fields from the fine-mesh (10 km) model ALADIN with hourly routine observations arising from a mesonet of automated ground stations. Concerning the analysis statistical model, adjusments of guess fields and observations errors variances. and of observations weight functions are required in order to obtain meteorological fields (such as temperature and humidity at 2 metres and wind at 10 metres) that fit convective system scales. Then, we evaluate, through case-studies, diagnostic fields such as Convective Available Potential Energy (CAPE) and MOisture CONvergence (MOCON), which are relevant in predicting convection triggering. These analysed fields are compared with radar reflectivities observed from 1 to 5 hours later, so as to estimate the skill of these parameters in predicting convective events.
The first results have already shown, in a qualitative way, that these diagnostic fields can provide useful guidance in determining where convection will occur. Further topics currently under study include designing a methodology for the use of such analyses in an objective way, and the parallel definition and computation of objective scores.

A NEW VARIATIONAL APPROACH TO DEDUCE THREE-DIMENSIONAL WIND FIELDS FROM AIRBORNE DOPPLER RADAR OBSERVATIONS OVER COMPLEX OROGRAPHY

J.F. Georgis and F. Roux (Laboratoire d'Aerologie, UMR CNRS/UPS 5560, Toulouse, France)

This work represents a contribution within the frame of MAP (Mesoscale Alpine Programme) so as to prepare the Special Observing Period (Fall 1999). A numerical investigation is carried out to study the feasibility of airborne Doppler radar observations over complex orography. The main problem with airborne (or ground based) Doppler radar observations relates to the exponential error growth in the vertical velocity due to the integration of the continuity equation. Numerical techniques have been developped to handle this in the case of a flat lower boundary condition (e.g. observations over oceans or plains), but the presence of significant orography makes this problem more difficult to solve. A new technique, based on a variational approach permits to obtain reliable values of the vertical wind component and to insure mass balance in the considered domain. This method is tested with simulated flows over simulated terrains, and actual data from a test flight over the Rocky Mountains with the French-American ELDORA-ASTRAIA airborne doppler radar.

Global mean generation of kinetic energy of sub-gridscale processes

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In the classical Lorenz energy cycle the generation rate G of available potential energy APE and its conversion rate C into kinetic energy KE have been evaluated on the gridscale. Both the potential and kinetic energies of sub-gridscale motions (APEsub, KEsub) have been considered as forms of internal energy. Thus the corresponding quantities Gsub and Csub have never been explicitly calculated.

However, this restriction makes both G and C scale-dependent. Further, it is unsatisfactory to exclude Gsub and Csub which are active within thunderstorms or cross-frontal circulations from the global energy cycle.

Here we try to augment the gridscale Lorenz energy cycle by its sub-gridscale counterparts. We employ a mesoscale diagnostic model that solves the moist enthalpy equation for the sub-gridscale fluxes in the atmosphere. By means of these fluxes we calculate the global conversion integrals. Input data are global analyses of T, q and wind plus forecasts of radiative heating and of the surface latent and sensible heat fluxes.

In a first step (August 1991, ECMWF initialized analyses) we have estimated the classical Lorenz quantity C=2.3 +/- 0.1W/m^2. The best estimate of Csub is 2.8 +/- 1.8W/m^2, thus contributing significantly to conversion rate into kinetic energy. Currently, it is tested if Csub is insensitive enough against uncertainties in the input forecast radiative heating fields.

AN IMPROVED AIRCRAFT THERMOMETER FOR IN CLOUD MEASUREMENTS WITH CENTIMETER RESOLUTION.

K. E. Haman and S. P. Malinowski (Warsaw University, Institute of Geophysics, ul. Pasteura 7, 02-093 Warsaw, Poland)

An improved version of the ultra-fast aircraft thermometer (UFT) with time constant better than 2*10-4 will be presented. Its sensor is a resistance thermometer made of platinum coated tungsten wire, (2.5(m, l=5mm, located on a rotatable vane and protected against droplets with a thin rod. The previous version of the thermometer worked well at airspeeds up to 40m/s. In the new version an improved design of the anti-droplet protection reduced significantly the aerodynamic noise at higher airspeeds. This allows to use the sensor at airspeeds up to 100m/s with resolution better than (0.2C.

CONVECTIVE ACTIVITY QUANTIFIED BY SUB-GRID-SCALE FLUXES

F. Hamelbeck and M. Hantel (Institute of Meteorology and Geophysics, University of Vienna, Vienna, Austria)

Large amounts of CAPE may be stored in the atmosphere, before the energy is released. In regions, where the timescale of storage is short, the static quantity CAPE is a good measure of convective activity. Elsewhere (e.g. in the extratropics) the dynamical process cannot be described by a static measure. A proper dynamic measure is the time correlation of the vertical velocity with a suitable energy quantity. We consider the vertical sub-gridscale flux of equivalent temperature (referred to as *convective flux*), as a means to quantify the convective process.

Here we compute the convective flux within atmospheric columns from the gridscale budget equation by an indirect technique, using routine analysed fields (e.g. ECMWF). Boundary value is the latent plus sensible heat flux across the earth's surface. Lacking observations of this latter flux, its value is specified by prognostic models as a substitute.

We will present results for columns (55km/12h) over Europe (MAP, BALTEX), where large amounts of CAPE may be accumulated. We shall demonstrate the kind of insight into the meteorological situation, which may be gained using the convective flux. For example, upward 2s fluxes exceeding $400\,W/m^2$ are found in cases of deep convection accompanied by strong precipitation. In another example (boundary layer convection, no rain) the upward surface flux of $200\,W/m^2$ decreases linearly and vanishes at about 900 hPa.

THE MET OFFICE'S UPGRADED LIGHTNING LOCATION SYSTEM.

G. L. Hamer (Met Office, London Road, Bracknell, Berkshire, RG12 2SZ, UK)

The Met. Office (UK NMS) has operated an 'arrival time difference' thunderstorm location system since 1986. This system's hardware is currently being upgraded to enable fully automatic operation and increase the number of lightning strokes that may be processed per hour from 400 - 500 to 10000 - 12000.

Software has been developed to allow flash type (cloud to ground or cloud to cloud), stroke polarity, stroke strength and the number of strokes per event to be determined over the UK.

A VLF propagation model is being developed to minimise the location errors introduced by long wave paths within the earth - ionosphere wave guide.

LARGE EDDY SIMULATION OF THE CONVECTIVE BOUNDARY LAYER OVER PARTIALLY ICE COVERED WATER

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We have investigated the development of a convective boundary layer during a cold air outbreak over a water surface partially covered by sea ice with a three dimensional LES model. These inhomogeneities which are often found in the marginal ice zone lead to strong horizontal gradients in the surface heat flux especially during cold air outbreaks. Our analyses focussed on how the inhomogeneous surface affects the turbulence structures and the horizontally-averaged variances, covariances and third moments. Compared with a homogeneous water surface the most pronounced differences occur when the scale of the surface inhomogeneities is comparable to the height of the boundary layer. In such cases the mean circulation as well as the variances of temperature and vertical velocity are increased.

AIRBORNE MEASUREMENTS OF LIGHTNING PRODUCED NO_X DURING LINOX

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Lightning is the most important NO_X ($NO+NO_2$) source in the upper troposphere (2-20 Mt N yr^{-1}). However, there is a need for a more accurate estimate of this NO_X source especially for the use of this parameter in chemical and climate models. The field experiment **LINOX** (Lightning produced NO_X) was performed in July and August 1996 over southern Germany and Switzerland to study the production of NO_X by lightning and the transport in convective storms. The research aircraft Falcon of DLR (Deutsche Forschungsanstalt für Luft- und Raumfahrt) penetrated about 20 anvils and measured besides the standard meteorological parameters various trace gases including NO_X (Chemiluminescence), CO_2 (IR-absorption) and O_3 (UV-absorption). NO enhancements of 0.5-1.5 ppbv were observed in smaller isolated anvils (10-15 km) with low lightning activity. A considerable part of these enhancements can be attributed to the transport of polluted air from the Planetary Boundary Layer using CO_2 as tracer. Measurements in more extensive anvils (20-50 km) organized in lines showed NO enhancements of 1.5- 4 ppbv where the major increase is due to lightning. A decrease in O_3 was observed during most penetrations due to transport of O_3 poor air from the PBL. The reduced horizontal wind speed measured in all anvils indicates transport of air of lower momentum from lower altitudes. The results from this study can be used to quantify the NO_X production per thunderstorm to estimate the annual NO_X production due to lightning for Germany.

CLOUD TO GROUND LIGHTNING ACTIVITY AND RADAR OBSERVATIONS OF STORMS IN THE PYRENEES RANGE AREA

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Recent works have studied the correlation between lightning and precipitation rates. The present research relates to the same issue in the Pyrénées range. We consider in this study: (i) the electrostatic field at the top of the Pic du Midi; (ii) the spatial and temporal location, and the polarity of cloud-to-ground discharges as detected by the Météorage network. The microphysical evolution of the cloud systems is observed by the MétéoFrance radars located in Toulouse and Bordeaux. Toulouse 5.2 cm radar provides panoramic cross sections at 3 elevations angles every 5 min, while Bordeaux 10 cm radar performs a panoramic cross section every 15 min. The vertical distribution of the precipitation within the clouds is deduced from the radar data, and the cloud-to-ground lightning flash rate (CGLFR) over a given area is provided by the Météorage data. Most case studies relate to isolated convective cells, but a mesoscale convective system (MCS) has been documented. Generally, in isolated convective storms, the cloud-to-ground lightning flash activity reaches its maximum when the radar reflectivity detected from precipitation at 6000 m is maximum, which happens before the precipitation growth at lower levels. The electrification of the thundercloud is probably due to the large ice particle concentration aloft. If a simple relationship is observed between the precipitation content and the CGLFR in the case of isolated cells, it looks more difficult to do the same for a MCS. This different behaviour indicates that the CGLFR is not a sufficient indicator of the MCS's electrical activity.

ABOUT THERMODYNAMIC PARAMETERS ESTIMATION WITHIN SHALLOW CONVECTIVE CLOUDS

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Numerical modelling is used to simulate main features of the vertical thermodynamic profiles in small cumulus. A particular attention is paid upon the peculiarities of the cloud LWC profile. Calculations are performed with a help of the Lagrangian two-dimensional model of the atmospheric shallow convection (Mostovoi, 1996) under different conditions of large-scale stratification in the environment. A Lagrangian approach makes more clear a formation of any cloud variable field from the viewpoint of air parcel history. The integration domain has a size of 2x2 km^2 with a grid resolution of 20 m in both coordinates. With this spatial resolution it is possible to resolve explicitly the mixing phenomena between cloudy air and the environment. Typical thermodynamic patterns produced by an isolated cumulus (growing from a thermal with a specified dimension and buoyancy) are compared with that of small clouds population generated by random surface heating. A comparison is made with similar profile estimations provided by one-dimensional, steady-state cloud model. The principal differences are revealed in vertical profiles of the various thermodynamic cloud parameters. Some implications for the cumulus LWC diagnosis and parameterization are discussed.

A LOGISTIC REGRESSION MODEL APPLIED TO SHORT TERM FORECAST OF HAIL RISK

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J. Marcos, M. T. de la Fuente, A. Castro (Applied Physic Dep. University of Leon. Spain)

In areas where high-quality agricultural products are grown that are also highly susceptible to hailfall damage, short-term forecasting is a prerequisite, in order to evaluate the risk of hail falling in cases such as this, where a relationship obtains between a response variable and one or more explanatory variables, and the outcome variable is also binary (risk/no risk), the Multiple Logist Regression Model is a good tool to use. A collection of 15 independent meteorological variables obtained from a sample of 208 local radiosondes carried out over as many days, was used to construct the model. The determination of risk/no risk situations was based on the meteorological information supplied by a dense network of over 500 observation points, distributed across an area of more than 6,500 km^2.

Many distribution functions have been proposed for use in the analysis of a dichotomous outcome variable, but for the present model, logistic distribution was eventually selected. After applying the model to forecast risk/no risk of getting hailfall on the target area, the results recorded show a True Skill Score of 0.8736 for the sample of 208 cases analyzed.

THE DISTRIBUTION OF RAIN CELLS BY SIZE

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The distribution of rain cells is closely associated with the distribution of convective cells. The object of the paper is to present a body of results on the rain cell size distribution (RCSD) in tropical and mid latitude areas deduced from radar data. It is shown that N(D), the cell number as a function of the equivalent circular diameter, is correctly represented by an exponential distribution and that the slope of N(D) is almost independent of the season and the geographical location. We demonstrate that the area occupied by the precipitation with rain rate above a threshold τ as well as the area-average rain rate can be written as functions of the only parameters of the RCSD.

CAPE AND CO_2 — DO MORE GREENHOUSE GASES LEAD TO MORE VIOLENT STORMS?

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The convective available potential energy (CAPE) of a sounding is a measure for the potential severity of a storm developing in the given environment. It is often assumed that the mean CAPE of the atmosphere will increase in a warmer climate due to more greenhouse gases. Thus global warming is expected to be accompanied by more frequent and more violent convective storms. While a recent theoretical study by Rennó and Ingersoll (1996) supports this assumption the experiments of Robe and Emanuel (1996) with a cloud resolving model find very little sensitivity of CAPE to the solar forcing. We present simple scaling arguments to cast light on the basic physical processes which control the amount of CAPE in radiative convective equilibrium (RCE). With the help of a column RCE model we show that for today's climate increases in the CO_2 content of the atmosphere have very little direct effect on CAPE. Indirect effects and other relevant processes will also be discussed.

SEVERE HAILSTORMS ON BOTH SIDES OF THE ALPS: A COMPARISON USING RADAR AND SOUNDING INFORMATION

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One of the aims of the Mesoscale Alpine Programme is to gain a better understanding about the occurrence, development and forecasting of severe convective precipitation events in the alpine region. Since 1996 a composite image of three operational Swiss radars (north: Albis, La Dôle; south: Lema) is available every five min. For the first time the images allow the comparison of intense activity simultanously on both sides of the Swiss Alps. Within an area of 37'000 km^2 (each side) single hailstorm tracks are extracted (cell definition: radar echo contour of 47 dBZ within for at least 30 min an echo of 55 dBZ - a severity criteria meaning hail on the ground - is visible). The time and duration of occurrence, the length and area of storm track, the point of origin and decay, the direction and speed of movement and the maximum height of the 47 dBZ contour are available for the north-south comparison. Sounding information from Payerne (north) and Milano (south) are used to describe the mesoscale environment on days showing such severe cells. Some results: 197 cells were observed on 31 days in the north during May - September versus 66 cells on 20 days in the south. The percentage of small (<25 km length of storm track) and large cells (>75 km) was higher in the north whereas medium cells (25-75 km) were more frequent in the south. Prefered regions of origin are observed on both sides. A higher percentage (26 versus 17) of cells reached the maximum observable height of 12 km (47 dBZ) in the north although the mesoscale environment in the south was more instable and the wind regime was stronger as well. The investigation is intended to be continued during the coming hail seasons.

NUMERICAL SIMULATION OF THE VAISON-LA-ROMAINE INTENSE RAINFALL EVENT

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The Vaison-la-Romaine flash flood on 22 September 1992 resulted in 42 casualties, and major economic damages. The observed rainfall in this case reached 300 mm in 6 hours. It was generated by the combination of several mesoscale convective systems, ahead of a cold front associated with a cut-off low, and exhibited many stationnary features.

In many respects, the event appears to be prototypical of the intense rainfall frequently observed on the mediterranean belt of southern France every fall season. It has been therefore selected as one of the case studies for the preparatory phase of the MAP program.

The paper will present a summary of diagnostic studies of this case, and numerical results of several numerical models, including the most recent non hydrostatic model of the french atmospheric community, Meso-NH.

RADIATIVE-CONVECTIVE EQUILIBRIUM IN A 3 DIMENSIONAL CLOUD ENSEMBLE MODEL

A.M.Tompkins and G.C.Craig (Dept. of Meteorology, University of Reading)

A knowledge of radiative convective interactions is key to an understanding of the tropical climate. To address this a cloud ensemble model has been run to a radiative- convective equilibrium state in three dimensions. The model has a resolution that is sufficient to resolve cloud-scale eddies and includes a 3-phase bulk microphysical scheme, and a fully interactive broad band radiation scheme for both the infra-red and short-wave. The control simulation is performed using a fixed sea-surface temperature (SST), and the surface fluxes calculated using the Monin-Obukhov formulation. The equilibrium of the control experiment is examined in terms of mean state statistics (cloud areal coverage, relative humidity, CAPE and temperature profiles for example) and heat and moisture budgets of the cloudy and clear sky areas, with particular attention being attributed to the clear-sky water vapour budget since this largely determines the radiative clear-sky forcing in tropical regions.
Results from other simulations are then shown in which the SST is perturbed by +/- 1 K, and the effect on the equilibrium statistics and moisture and heat budgets is examined. Although the control simulation had vertical temperature and moisture distributions that were in line with tropical observations, it would appear that the model's vertically integrated water amount shows a greater sensitivity to changes in underlying SST than observed. With reference to the climate problem the magnitude of the cloud and water vapour feedbacks in this model are also discussed.

OA14 Numerical weather prediction

Convener: Gustafsson, N.
Co-Conveners: Macpherson, B.; Sunde, J.

LONG-RANGE NUMERICAL PREDICTION WITH A THERMODYNAMIC CLIMATE MODEL.

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A. Ruiz, V. M. Mendoza, R. Garduño, E. E. Villanueva (Same address)

A revised coupled ocean-atmosphere thermodynamic model is used to carry out monthly numerical predictions for extended periods as long as three months,as well as average seasonal predictions, in the Northern Hemisphere. The initialization data are the monthly values of sea surface, 700 and 850 mb temperatures, and the surface pressure, during the previous month and the horizontal extent of the snow and ice cover in the last week of the previous month, as well as the corresponding normal values. The model consists of an atmospheric layer of 10 km height, an ocean layer of 60 m depth, and a continental layer of negligible depth. The predicting equations are obtained applying the conservation of thermal energy to this climate system. The ocean equation is integrated explicitly with forward time steps of one day, and the atmospheric equation with backward time steps of one month and using an implicit method of integration. We use the NMC grid with 1977 points and a grid distance of 408.5 km. Verification of the predictions for the period from June 1980 to May 1984 of the sea surface temperature anomalies in the Pacific and Atlantic Oceans for the whole region of integration shows good skill. The evaluation of the monthly extended and seasonal prediction of temperature and precipitation anomalies in the Mexican Republic shows also good skill, which depends in an important way on the ocean temperature anomalies.

IMPACT OF OBSERVATIONS IN NWP MODELS

M.J. Bader and R.J.Graham (NWP Division, Meteorological Office, London Road, Bracknell, RG12 2SZ, UK.)

Many investigations to assess the impact of conventional, satellite and bogus observations on NWP model forecasts are reported in conference proceedings and unpublished internal reports. Results of such studies have therefore been collated into one report so that they can be compared. Over forty recent experiments, carried out at different centres worldwide, are presented as tables giving the reference, method, model used and results (i.e., sign, magnitude and location of the impact).

Most impact studies involve running models with and without the observation types being assessed and then verifying the forecasts. The two main techniques - the 'Observing System Experiment' (OSE) and 'Observing System Simulation Experiment' (OSSE) - are described. OSEs are used for assessing the impact of current observation systems as well as new observations and new methods of using them. OSSEs are used to evaluate the likely impact of proposed future observing systems.

It is hoped that the contents will help readers working, for example, in NWP modelling and observation assessment to gain a good grounding of impact study work and direct them to key references.

THE NEW 40KM, 40 LEVEL VERSION OF THE MESOSCALE ANALYSIS AND PREDICTION SYSTEM

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John M. Brown and Dezso Devenyi NOAA/FSL and CU/CIRES

A new, higher resolution version of the Mesoscale Analysis and Prediction System (MAPS, run operationally as the Rapid Update Cycle at the USA National Centers for Environmental Prediction), under development at the Forecast Systems Laboratory, has been running in continuous cycling mode for well over a year. This new version incorporates considerable additional physical parameterizations, including long and short-wave radiation, cloud and precipitation microphysics (both based on MM5 routines) and a multilevel explicit prediction of soil temperature and moisture with continuous cycling. This new version of the model outperforms the current operational RUC, and is expected to replace it in the near future. Remaining development issues will be mentioned and examples of model performance, including the soil component, will be shown.

LARGE SIZE, HIGH RESOLUTION ENSEMBLE PREDICTION AT ECMWF

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The new version of the Ensemble Prediction System (EPS) implemented at the European Centre for Medium-Range Weather Forecasts (ECMWF), is based on one integration starting from the unperturbed analysis (control), and 50 integrations starting from initial conditions defined by adding perturbations sampled in an unstable linear sub-space. More specifically, the 51 integrations are performed at T159 spectral resolution and with 31 vertical levels. The unstable sub-space comprises dominant singular vectors (SVs) growing in the first 48 hours of the forecast, computed at T42L31 resolution. This EPS configuration was introduced operationally on the 11th of December 1996, and constituted an upgrade of the system, which at that time was based on 32+1 integrations of a T63L19 model version. First, the ECMWF EPS is briefly described. Then, the impact of an increase of ensemble size and resolution of the performance of the ECMWF EPS are discussed.

THE UKMO'S VARIATIONAL DATA ASSIMILATION SCHEME

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The UKMO is developing a variational analysis (VAR) system to replace the existing analysis correction (AC) scheme in its operational Unified Model suite. Global and limited area versions of a three-dimensional system (3DVAR) are currently being tested. The control variable fields are currently streamfunction, velocity potential, relative humidity and unbalanced pressure. Each of these fields is decomposed first into vertical error modes and then horizontal spectral modes. In its initial operational implementation, expected towards the end of 1997, observations will be preprocessed onto model variable space in the same way as is done for the current AC scheme. We hope that we will be able to start assimilating satellite radiance observations directly a few months afterwards. In this paper, we present a description of the UKMO's VAR scheme and some results from tests of 3DVAR.

APPLICATION OF 3DVAR ANALYSIS IN THE MESOSCALE ANALYSIS AND PREDICTION SYSTEM

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Stanley G. Benjamin (NOAA/FSL, Boulder, Colorado, USA)

A 3-dimensional variational analysis method has been developed for application in the Mesoscale Analysis and Prediction System (MAPS), an operational high-frequency numerical forecast system in the USA using a hybrid isentropic-sigma vertical coordinate. The 3dvar method uses a physical space approach and the background error covariance matrix is approximated by filters. Relaxed geostrophy and hydrostatic constraints are used in the analysis increment space. For optimization, the conjugate gradient method is applied with the Polak-Ribiere modification. Results will be presented about the effectiveness of 3dvar in the MAPS environment using in situ (rawinsonde, surface, aircraft) and remotely sensed (various types of wind profiles and satellite) data. Characteristics of the 3dvar method versus optimal interpolation will be demonstrated using real-data results.

A COUPLED SINGLE COLUMN MODEL FOR LOCAL FORECASTING

C.C. Dunlop (Meteorological Office, London Road, Bracknell, England)

The UK Met Office currently runs a high resolution Mesoscale model which requires forecaster intervention for local sites smaller than the grid scale. In order to improve the quality of local model forecasts a 1D model coupled to the Mesoscale is being developed. The first version seeks to do this by taking more account of the local surface and modelling the near surface boundary layer more accurately. The model has high vertical resolution (71 levels) and uses mainly the same physics as the Mesoscale, with some improvements to the surface energy balance. The model is appropriate for use in non-frontal situations with limited horizontal advection where the boundary layer has time to respond to the local conditions.
A comparison of model forecasts for fog and minimum temperatures during Autumn 1996 is made with observed cases from MRU Cardington, Bedford and with both Mesoscale model forecasts and routine synoptic observations for a number of sites.

THE GLOBAL 3D VARIATIONAL ASSIMILATION SYSTEM OF THE CANADIAN METEOROLOGICAL CENTRE

P. Gauthier, C. Charette, P. Koclas. S. Laroche and L. Fillion (Data Assimilation and Satellite Meteorology Division, 2121 Trans-Canada Hwy, room 502, Dorval, P.Q., CANADA H9P 1J3)

A global spectral 3D variational analysis (3Dvar) is currently being tested for implementation at the Canadian Meteorological Centre to replace the operational analysis based on optimal interpolation (Mitchell *et al.*, 1996). The 3Dvar has been built to be first as close as possible to the operational system which has permitted to study the impact of data selection on the analysis. The main results are: i. the use of a linear balance relationship in the multivariate formulation leads to non-local correlations that can lead to a strong bias in the forecast, ii. the absence of data selection makes the analysis to react strongly to the presence of biases in the background field, iii. the analysis is very sensitive to the forecast error statistics. The forecast error variances for the streamfunction, the velocity potential and the geopotential departure from geostrophy vary in physical space zonally and in the vertical. The current work aims at improving these statistics by activating the divergent wind component in the analysis and by introducing a non-separable representation for the error correlations. This is done in conjunction with the development of an analysis performed directly on the levels of the model. Finally, it is worth mentioning that experiments are already being conducted to assimilate directly TOVS cloud cleared radiances and SSM/I data.

VARIATIONAL RETRIEVAL AND ASSIMILATION OF SSM/I TOTAL PRECIPITABLE WATER IN THE ECMWF MODEL

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A one-dimensional variational(1DVAR) method has been developed at European Centre for Medium-Range Weather Forecasts (ECMWF) for retrieving the atmospheric humidity profile, the surface wind speed and the cloud liquid water path from Special Sensor Microwave/Imager (SSM/I) observations over ocean. This method is based on nonlinear optimal estimation theory and is a simple way of extracting information from SSM/I radiances, exploiting the high quality a priori information available from the ECMWF forecast model. Results of TPW assimilation experiments in the ECMWF model will be available at the time of the meeting; it is expected that through the assimilation of TPW either obtained from 1DVAR or from a statistical regression the model dry bias is reduced, especially in the Tropics.

THE UTILITY OF OBSERVATIONS FOR MESOSCALE MODEL FORECASTS OF PRECIPITATION ACCUMULATION: PRELIMINARY RESULTS

R.J.Graham, S.R.Anderson, M.J. Bader and B. Macpherson (NWP Division, Meteorological Office, London Road, Bracknell, RG12 2SZ, UK.)

A program of data impact case studies is being carried out to help assess the relative utility of existing observation types for forecasts of 3-hr precipitation accumulation from the UK Met. Office Mesoscale NWP model. The study forms part of a project to guide the rationalisation of the UK observing network.
Cases are selected from past operational forecasts for which the observed rainfall was widespread, and for which data are known to have had a marked positive impact on model skill. Impacts at two forecast ranges, 6hrs and 12hrs are considered. Skill is assessed against an analysis of 3-hr rainfall accumulation from the UK weather radar network. The measure of skill used is the Equitable Threat Score.
The aim of each case study is to identify the impact of each observation type when used alone in the assimilation. The frequency, over all cases, with which observation types deliver a significant benefit is then used as a measure of observation utility. Results so far indicate that humidity profiles are more effective than other observation types at improving forecasts of the general location of precipitation; while radiosonde wind and temperature profiles and surface information are the most effective for improving forecasts of precipitation of moderate or heavy intensity.

MOUNTAIN WINDS: OBSERVATION AND MODELLING

E. Hernández, J. de las Parras, I. Martín, A. Rúa, J. Díaz.
(U.C. M., Facultad de C.C. Físicas, Cátedra de Física del Aire)

Wind data collected in a mountainous area are used to investigate the mean properties of the flow on two typical summer days when the wind at ridgetop had a perpendicular component to the ridge. The overall objective of the study is to develop a wind model. One of its applications will be to supply surface wind fields to a forest fire simulator. This model has been developed with the premise that in mountainous terrain the wind on a given point can be considered as the result of vector addition of a large scale flow modified by the local topography and the different components of the wind generated by the subgrid-scale inhomogeneities of the ground surface. Functions that include the topographic effects of sheltering and deflecting and the generation of slope flows have been formulated. The model is considered a physical-mathematical model coupled to the output of a mesoscale prediction model. The model outputs are presented and compared with the experimental data.

A GENERALIZED SCHEME FOR A SIMPLIFIED 4-DIMENSIONAL VARIATIONAL DATA ASSIMILATION SYSTEM

Xiang-Yu Huang (Danish Meteorological Institute, Denmark)

A generalized scheme is proposed for the Poor Man's 4-dimensional Variational data assimilation system (PMV) of Huang *et al.* (Huang, X.-Y., Gustafsson, N. and Källén, E. 1996: Using an adjoint model to improve an optimum interpolation based data assimilation system. *Tellus*, in press). The new scheme is referred to as GPV and has the same basic idea as that of PMV, i.e., to use an adjoint model to improve an Optimum Interpolation (OI) based assimilation system. In addition, GPV includes the possibility of using different forecast models in the original OI based assimilation system and in the new variational component of the scheme. This generalization leads to three advantages over the original setup: 1) a wider application of an adjoint model developed for a particular forecast model; 2) an implementation flexibility due to its incremental nature; 3) a considerable CPU saving if the variational component is run on low resolutions.

CALCULATING A FICTIVE OPTIMAL OROGRAPHY USING THE NUDGING TECHNIQUE

E. Kaas and **M. Barfred** (Danish Meteorological Institute, DK-2100 Copenhagen O, Denmark)

A simple four dimensional data assimilation technique ("nudging") has been used to deduce a (fictive) orography which will minimize the forcing errors in a global shallow water model.
When assimilating observed data into an atmospheric model using nudging one obtain as a bi-product the forcing needed to make the model resemble nature, i.e. the forcing error of the model. Analysing the spatial and temporal behavior of this error it is possible to determine errors in those terms in the model equations which formally reflects a mountain form drag. These are of course only errors in the sense that they reflect systematic errors in the model's efficient form drag and there is no a priori guaranty that they reflect the real mountains in nature.
The nudging technique has been applied to a version of our shallow water model with no orography at all in order to calculate the entire orography solely from observed atmospheric data. The resulting orography is not identical to but corresponds quite well with the true mountains.
Defining model consistent orography is particularly important in climate models which are severely truncated. The current work on the shallow water model should be seen as a benchmark of a more complete future work aiming at defining the optimal orography needed in climate models.

USE OF A COLUMN MODEL TO SUPPORT MORE ACCURATE TERMINAL FORECASTS OF STRATUS BURN OFF TIMES FOR THE SAN FRANCISCO INTERNATIONAL AIRPORT*+

John L. Keller (MIT Lincoln Laboratory, Group 43, Weather Sensing, Lexington, MA, USA 02173-9108)

Sea fog, associated with a shallow marine boundary layer, is present during much of the warm season (May through September) along the California coast. Often the marine boundary layer extends inland into the San Francisco Bay area and can support the overnight formation of shallow stratus-like cloud layers. A late burn off of this stratus cloud can have significant implications for air traffic control at the San Francisco International Airport. We are developing an operational column model to support short-term forecasts of when the stratus will burn off. A modified version of the Oregon State University column model is being adapted for this role. As part of this effort an operational meso-net has been established. Additional sensors support column models at two locations that are considered critical to developing accurate stratus burn off forecasts. These two column models have been operating in real time since early September of 1996. This presentation will summarize the results from several diagnostic studies and the first year's operational evaluation.

* This work was sponsored by the Federal Aviation Administration. The views expressed are those of the author and do not reflect the official policy or position of the U.S. Government.

+ Opinions, interpretations, conclusions, and recommendations are those of the author and are not necessarily endorsed by the United States Air Force.

A REGIONAL 3D VARIATIONAL ASSIMILATION SYSTEM BASED ON THE INCREMENTAL APPROACH

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At the Canadian Meteorological Center (CMC), global and regional forecast models are run twice a day to provide weather predictions to the national weather offices located throughout the country. A 3D variational analysis (3Dvar) for the spectral global model is currently being tested for operational implementation (Gauthier et al. 1997). Along with this system, a regional 3Dvar based on the incremental approach is also developed for a regional grid point model. In this approach, the innovations are computed in observation space with respect to the background state at the full resolution of the model, whereas global analysis increments are calculated at a lower resolution with only minor changes to the global 3Dvar system. This approach for regional analysis is justified by the fact that, under the isotropy and homogeneity assumptions for the forecast error statistics, a spectral resolution of T108 is sufficient to properly resolve the analysis increments. The regional 3Dvar system is being tested for the new global finite element (GEF) model that focuses over North America at a resolution of 35 km typically. Results obtained so far show that it is possible to assimilate observations over a limited area while using a global representation for the analysis increments. Two types of assimilation cycle are evaluated: a continuous cycle such as the one used for the global model and a 12 hours spinup procedure such as described by Chouinard et al. (1994).

FORTHCOMING DEVELOPMENTS IN THE UK METEOROLOIGCAL OFFICE OPERATIONAL NWP FORECAST SYSTEM

S. J. Lorrimer, S. F. Milton and C. A. Wilson (NWP Development Division, UK Meteorological Office, London Road, Bracknell, Berkshire, RG12 2SZ, UK.)

The UK Meteorological Office (UKMO) is currently taking delivery of a Cray T3E massively parallel supercomputer. To make best use of this new resource we are planning to increase the resolution of the global forecast model from 90km at mid-latitudes with 19 vertical levels to 60km with 30 levels. This is of a similar resolution to the current regional forecast system, covering the North Atlantic and Western Europe. In this presentation we discuss some results from the ongoing assessment of this change. We show that these changes will lead to improvements in the quality of numerical guidance issued to forecasters, particularly in relation to upper troposphere winds and mean sea level pressure forecasts.

DATA ASSIMILATION ALGORITHM BASED ON THE SIMPLIFIED VARIANT OF KALMAN FILTER

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The suboptimal data assimilation algorithm is consided. This algoritm is an extended Kalman filter for the vertical normal modes coefficients with a simplified model for the calculation of the forecast error covariences. The calculation of the forecast error covariances is based on the assumption that the errors of vertical normal modes don't correlate with one another. In numerical experiments the 15-level regional model of the atmosphere described by primitive equations is used. This forecast model is based on the splitting method into the physical processes and only the advection step is used for the calculation of the forecast error covariences.
By this algorithm identical twin experiments have been made.

A STUDY OF THE BEHAVIOUR OF SEMI-LAGRANGIAN MODELS IN THE PRESENCE OF OROGRAPHY

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J.R Bates (Department of Geophysics, University of Copenhagen, Juliane Maries Vej 30, 2100 Copenhagen Ø, Denmark)

Orography has been incorporated into two global shallow water numerical models, the first [termed the (u,v) model] based on a semi-Lagrangian vector discretization of the momentum equation, the second [termed the (PV-D) model] based on the semi-Lagrangian advection of potential vorticity. Numerical integration of the models with zero or small uncentering show that they have quite different orographic noise characteristics. The noise in both models can be eliminated by a sufficient amount of uncentering. The PV-D model allows the use of a scheme in which only the divergence and continuity equations are uncentered. With this, the large scale Rossby waves, which are negatively influenced by the effects of uncentering, are shown to be more accurately simulated.

INITIALIZATION OF THE DWD LOKAL-MODELL USING A DIGITAL FILTER.

Peter Lynch (Met Éireann, Dublin, Ireland. (plynch@irmet.ie))

Günther Doms (Deutscher Wetterdienst, Offenbach-am-Main, Germany)

An initialization scheme for a non-hydrostatic NWP model has been developed using the digital filtering technique. The method is described and results of an application to the Lokal-Modell of Deutscher Wetterdienst are presented. Emphasis is placed on the impact of initialization on moisture and precipitation and upon non-hydrostatic effects.

The DFI technique has important advantages relative to the widely-used normal mode initialization (NMI) method. Since knowledge of the model linear modes is not required, they need not be calculated or stored. Thus, DFI can be applied to models with irregular boundaries, with non-uniform grids, with non-separable horizontal structure and with arbitrary vertical discretisation. All prognostic variables are filtered in DFI. Thus, a consistent balance between humidity, clooud water, etc., and the dynamic fields can be established. Therefore, DFI has greater potential than NMI to alleviate the spin-up problem. Application to non-hydrostatic models is straightforward for DFI: the additional prognostic variables are filtered in the same way as the conventional variables.

THE HIRLAM ANALYSIS AND FORECASTING SYSTEM: A REVIEW

Peter Lynch (Met Éireann, Dublin, Ireland (plynch@irmet.ie).)

The HIRLAM (High-Resolution Limited Area Model) analysis and forecasting system is under continuing development in a cooperative research project among nine European NMSs. A major component of the research effort is devoted to developing a 4D-Variational assimilation system. Progress to date will be described and illustrated by case studies.

Version 3 of the forecast model has recently been finalized. It includes

- A new surface parameterisation scheme
- A new physiography processing method
- A new boundary layer turbulence scheme
- A new mass-flux convection scheme
- A semi-lagrangian advection scheme

A comprehensive parallel evaluation has shown that Version 3 is superior to the earlier reference model. The principal characteristics and properties of the HIRLAM model will be outlined and some sample forecasts will be used to illustrate the characteristics of the new model.

DEVELOPMENTS IN THE ASSIMILATION OF SATELLITE IMAGERY AT THE UK MET OFFICE

B. Macpherson, K. Whyte and B. W. Golding (NWP Division, Meteorological Office, London Road, Bracknell, RG12 2SZ, England)

A cloud analysis derived from Meteosat infrared (IR) satellite imagery and surface reports has been part of the mesoscale data assimilation system at the UK Met Office for several years. Recently the cloud analysis system has been developed to include visible (VIS) and water vapour (WV) imagery. VIS imagery helps with cloud detection when the cloud top and the sea surface are at a similar temperature, and cloud detection from IR alone is unreliable. WV imagery is used in conjunction with IR to improve the height assignment of semi-transparent cirrus or sub-pixel cloud. With IR data alone, such cloud can be wrongly assigned to medium levels, causing spurious convection in the model. A large-area cloud analysis has also been implemented operationally in the UK Met Office regional model. Its domain covers the Bay of Biscay and the data give some valuable forecast impacts in summer cases with slow-moving, thundery systems.

TESTS OF THE VERTICAL DIFFUSION SCHEME BASED ON $E - \epsilon$ APPROACH IN 3-D HIRLAM

V. Perov, B. Bringfelt and K.-I. Ivarsson (Swedish Meteorological and Hydrological Institute, Folkborgsvägen 1, S-60176 Norrköping, Sweden)

The parameterization of vertical diffusion based on the $E - \epsilon$ approach has been installed in 3-D HIRLAM. It uses two prognostic equations for turbulent kinetic energy and dissipation including advection and no mixing length assumption. A stable implicit numerical method of a Crank-Nicholson type has been developed for the prognostic equations in the vertical. A case study is based on results of 30 hours weather forecast by 24 and 40 vertical levels and 22 km horizontal resolution HIRLAM model for the European-North Atlantic- Greenland area for 25 August 1996. For comparison to the measurement data from the NOPEX project in 1994 and 1995, a higher resolution (5,5 km) version is tested covering a Southern Scandinavia. The new vertical diffusion scheme demonstrated advantages in predicting temperature, humidity and wind in the boundary layer and in the top troposphere, compared to a first order K-theory scheme.

CLEAR SKY IASI INFORMATION CONTENT. A POTENTIAL FOR NUMERICAL WEATHER PREDICTION

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IASI (Infrared Atmospheric Sounding Interferometer) is the European project for an improved infrared atmospheric sounder. It is designed to provide temperature and humidity profiles with an improved accuracy and vertical resolution. The estimation error covariance matrix associated to the analysis of the atmospheric state is used on one particular meteorological situation to examine the potential benefit of radiance data information for numerical weather prediction. The gain of information content obtained from simulated IASI data is studied and compared to the current information content present in the TOVS radiances.

19 independent pieces of information on a typical temperature/humidity profile are available from the IASI data, compared to 5 from the TOVS data. In terms of temperature, fine scales structures associated to a vertical resolution of 1 km are estimated with a 0.7K error standard deviation. The gain of information for specific humidity is of the same order of magnitude as for temperature. Typically, humidity structures associated with 1 km vertical resolution scale are estimated with a relative error of 16 %.

The projection of the analysis error covariance matrix on atmospheric error structures (relevant for numerical weather prediction) gives a measure of the impact of the use of radiances on the observability of such structures. The results indicate that IASI data would be a decisive source of information for the analysis of such structures.

VALIDATION OF SEMI-LAGRANGIAN AND EULERIAN ADVECTION SCHEMES VIA SIMULATIONS OF ROTATING, STRATIFIED FLOW IN THE LABORATORY

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Laboratory experiments on rotating, stratified flows can be carried out under well controlled conditions, and can be made to exhibit a number of dynamical instabilities of interest to meteorologists. Well resolved spatio-temporal measurements e.g. of velocity and temperature can be made in such experiments, overcoming a number of difficulties in the conventional procedures used to validate components of numerical models used for weather prediction associated e.g. with inadequate coverage of observations. Numerical simulations of such flows also require no controversial parametrizations, so that attention can be clearly focussed on validating the resolved components of the simulation. In the present work, various forms of semi-Lagrangian advection have been incorporated into a numerical model of baroclinic flow in a rotating, cylindrical annulus. Cases will be presented comparing simulations which use semi-Lagrangian schemes for temperature and/or momentum advection with those using more conventional Eulerian schemes, and with high precision measurements of velocity, temperature and heat transport in the laboratory. Initial emphasis will be placed on simulations of zonally-symmetric flows, but our ultimate aim is to evaluate semi-Lagrangian simulations of fully three-dimensional baroclinic flows against laboratory measurements.

Doppler winds and the numerical weather prediction

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As far as the author knows, the wind observations from Doppler radars are not used in routine data assimilation systems. When applying Doppler winds in the data assimilation, the focus should be in the mesoscale systems. Reasons for and consequences of this conclusion are presented. In a case study, the Doppler winds are computed from observations made during one sweep at the lowest elevation angle. There turns out to exist a certain radar circle, for which the VAD method gives winds suitable for data assimilation. Observations at circles closer to the radar are sensitive to small scale phenomena such as convection. Winds computed at circles further away may include errors due to vertical and horizontal smoothing.

NUMERICAL MODELLING OF ATMOSPHERIC PROCESSES FOR SIBERIAN REGION

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The modern state of ICT SB RAS system MAP of the numerical modelling of the atmospheric processes and the aerosol transfer in the Siberian region for carrying out of the expert estimates with the help of observing meteodata and the contaminants ejections into the atmosphere is described. The basic components of this system are the following: scheme of numerical analysis (3-dimensional optimal multivariate interpolation); initialization scheme (the normal modes); model of the atmosphere (15 levels, D - grid, Marchuk splitting-up method); block of the aerozol transfer (Bott scheme, the splitting-up method). Methods of solution and the rezults of experiments with assimilation of the real data are presented also.

Application of Meteosat WV images in monitoring of synoptic scale split flow cyclogenesis. A case study.

ABSTRACT.

The use of the potential vorticity concept is recognised as beneficial in gaining understanding of dynamical and physical processes in the atmosphere. However, to improve the weather forecasts, means of verification of the Numerical Weather Prediction (NWP) model derived PV- fields are required. Use of satellite data is considered as a very useful tool for this task. Particularly WV images from geostationary satellites appear very promising in this field and constitute a potential for further improvements of evaluations of NWP models. Upper air PV anomalies associated with tropopause foldings originate from the stratosphere and contain very dry air. They consequently appear as dark regions in the WV - images in the rear of developing cyclones, also the position of the jet stream can readily be inferred from the images. A case study of a split flow cyclogenes is investigated. This weather situation was initially poorly forecasted by the numerical model. The model failed to catch the southern branch of the split flow which could be identified in the WV image. Earlier studies have shown that we may have confidence in the NWP model forecasts when there is a high consistence in space and time between model output showing areas with high level potential vorticity and the dry areas inferred from the WV images. However, when such correspondence is only poor, the confidence is shown to be lower.

RESPONSE OF DIFFERENT ACOUSTICALLY FILTERED HIGH-RESOLUTION PRESSURE–COORDINATE MODELS TO THE OROGRAPHIC FORCING

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The Least Action (Hamiltonian) Principle is employed to get the acoustically optimum-filtered nonhydrostatic pressure-coordinate model (OFM). In the OFM the quasistatic balancing of the pressure force is used for the filtration rather than incompressibility of motion in the p–space. To estimate the accuracy and efficiency of the optimum filtration techique, model calculations with the OFM, hydrostatic primitive equation model (PEM), Miller-Pearce model, anelastic model, and exact nonfiltered pressure-coordinate model (ExM) are carried out. The linear response of the uniform flow to the orographic forcing for different filtered models is compared with ExM results. The OFM enables high accuracy, modeling error does not exceed a fraction of a per cent in the domain of orographic scales 100 m – 1000 km. Accuracy of other filtered models is more scale-sensitive. An unexpected result of simulation is that the PEM causes substantial error in the whole hydrostatic meso- and synoptic-scale domain, 30 - 1000 km, in the stratosphere and upper troposphere. This error is a result of the location of a characteristic equation singularity in the PEM at a finite horizontal wavelength, which in the case of the ExM is disposed at the infinity.

VERIFICATION OF NEAR-SURFACE WEATHER ELEMENTS OF THE SM (SWISS MODEL) WITH HOURLY OBSERVATIONS OF THE AUTOMATIC NETWORK OF THE SWISS METEOROLOGICAL INSTITUTE

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The Swiss Model (SM) is a hydrostatic meso-β scale numerical weather prediction model (grid mesh about 14 km) operationally used at the Swiss Meteorological Institute (SMI). It has been developed in a joint effort by the Deutscher Wetterdienst (DWD) and the SMI as a high-resolution version of the Europa Modell of the DWD. In a slightly different configuration the same model is run at DWD under the name Deutschland Modell.
The near-surface weather elements 2m-temperature, 10m-wind and total precipitation of the SM are verified on an hourly basis with observations of the automatic network of the SMI (ANETZ). Total cloudiness is verified against 3-hourly eye-observations at ANETZ locations. The verification package will be described (correspondency of SM-grid points to ANETZ observations) and results of winter 96/97 and summer 96 shown: mean hourly daily variations of these near-surface weather elements, errors in bias and standard deviation, for precipitation and cloudiness also contingency tables and resulting scores (frequency bias, threat score). Results are distinguished between three height class regions: Swiss Middleland (< 800m), Prealps (800-1500m) and Alps (>1500m). As an example, just one typical result of summer verification: The increase in 2m-temperature in the morning hours starts too rapidly in the model, probably due to the underprediction of dew in the model.

A REGIONAL, SPECTRAL SHALLOW-WATER-MODEL WITH NON-PERIODIC, TIME-DEPENDENT BOUNDARY CONDITIONS

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We use a three-layer shallow-water-model to study the flow in regions with complex orography. Two new numerical methods are applied in this model: i) The flux correction scheme of Schmidt to avoid the occurrence of 'negative layer heights' in regions where the fluid depth is extremely small and ii) the extension technique proposed by Haugen and Machenhauer, which allows a spectral model based on double Fourier series to handle non-periodic boundary conditions. Therefore, the model makes use of the high order of accuracy in computation of the derivatives of the spectral method for a regional model.
Preliminary results of different flow simulations are presented. In particular, cross-Alpine flows with time-dependent lateral boundary conditions are shown.

A RETROSPECTIVE PHYSICAL–SPACE STATISTICAL ANALYSIS SCHEME

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The Physical–Space Statistical Analysis System (PSAS) of the NASA's Data Assimilation Office (DAO) is designed as an incremental improvement over the Optimal Interpolation (OI) based data assimilation system. The primary difference between OI and PSAS is that the latter uses a global conjugate gradient solver that includes all available current observations to produce the current analyzed field. Both OI and PSAS are, in general, suboptimal filters, for they use data from the current time to produce the current analysis. On the other hand, the fixed–lag Kalman smoother of Cohn–Sivakumaran–Todling (*Mon. Wea. Rev.*, 1994, pp. 2838–2867) is an optimal retrospective data assimilation scheme which incorporates data well past each analysis time in addition to the present and past data to improve a number of past analyses. This optimal scheme, however, cannot be used as it is with PSAS to produce retrospectively analyzed data sets, for it requires manipulation of several large matrices. Here we derive a new scheme which uses vectors instead of matrices but adopts the main framework of PSAS to perform fixed–lag retrospective data assimilation. Therefore, this new scheme can be annexed to DAO's PSAS to produce retrospectively analyzed data sets.

QUASI-SYNCHRONOUS MODEL FOR MONTHLY WEATHER FORECASTING

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The nonlinear nature of the atmospheric processes makes all atmospheric motions to be chaotic and, at the same time, self-similarly ordered over wide range of space and time scales. The quasi-hydrostaticity and the quasi- gtostrophicity are the well-known manifestations of the ordering. It is less known that an order also is a property of the lower-frequency atmospheric dynamics. Our modelling and diagnostical studies have revealed that the motion of the different waves with the same zonal wave numbers are synchronized over the time scales up a week. It can be assumed that such nonsynchronized motions are physically possible but nonobservable in reality because of their larger instability in comparison with the synchronized ones. This instability can shift the practical predictability limit of the planetary scale motions into an earlier time position as a consequence destroying the synchronization by inevitable noisy initial data of the weather forecasting models based on the primitive equations. So, it has been hypothesized that just this phenomenon of the artificial desynchronization of the modelled planetary wave motions is one of the important reasons of the complete predictability loss of the present-day forecasting models in a week of these models runs, and that a mutual synchronization of these motions is crucial in order to prevent the regrettable circumstance. TO examine the hypothesis a so-called quasi-sychronous model has been created. THe equations of the model are averaged with respect to the wave phases synchronizations of which were recognized in the real atmosphere. Despite it were taken into account only simplest newtonian-type forcings and topographical drag, and the spectral resolution of the model is very low, so the model ia a toy-model in fact, runs of the model with real initial data indeed demonstrate an ability of the model to overcome the weekly limit of predictability for the 5-day mean 500 hPa high fields of the Northern hemisphere extratropics. Of course, the forecasts make a caricature of the real dynamics, but some basic features of the latter are recognizable in the forecasts. Some examples of the operational forecasts for 40 days ahead will be shown as well as results of their interpretation in terms of the surface air temperature for Moscow.

OBJECTIVE CORRELATION OF VARIOUS ECMWF NUMERICAL PARAMETERS WITH METEOSAT IR IMAGES

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In the work presented here various numerical parameters and satellite images fields have been objectively correlated. This means that not only the intensity and the position of the maxima of some parameters were compared to the shape and position of the cloud structures, but also the exact values of the parameters were correlated with pixel values in the image. Statistical analysis was performed using pixel values from the infra-red Meteosat images and the parameter values from the analysis fields of vertical velocity ω, divergence, vorticity advection and the Q-vector normal component. Vertical velocity ω in 500 hPa shows the best correspondence with IR pixel values, especially in the regions where relative humidity is greater than 50%. The correlation between divergence and pixel values is best for divergence in 300 hPa and 850 hPa. Vorticity advection is very useful in cases of comma cloud structures, enhanced cumuli clouds and frontal intensifications caused by wave development or a jet-streak. Q-vector normal component shows the best correlation with satellite images in frontal cases. Due to its prognostic nature it can be applied for nowcasting purposes as the indicator of frontogenesis and frontolysis. A very useful value also observed in the analysis is the threshold pixel value in the satellite image. Pixel values higher then 169 obviously represent clouds for the data set used here. Threshold values for the investigated parameters are also discussed pointing out that all these values could find their application in the automatic satellite image analysis.

IDENTIFYING AREAS WHERE OBSERVATIONS CAN REDUCE LARGE FORECAST ERRORS

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Serious forecast failures are localized both in time and space. On the meso– and larger scales, these failures are largely associated with errors in the initial conditions (analysis) that amplify rapidly, rather than with model deficiencies. In this study we compare two simple techniques to identify in advance such potential forecast problems and to trace them back to their origin in time. The first technique is based on an ensemble of 14 perturbed forecasts that are available operationally at NCEP. Experience shows that as expected, large spread of the ensemble members around the ensemble mean indicates possible forecast failures. In cases when, say, the 72–hour forecast error is expected to be large, one can run a series of inexpensive singular value decomposition (SVD) calculations in the subspace of the nonlinear ensemble perturbations. In these calculations one can use a norm that maximizes perturbation amplitudes at final time in the critical forecast region while reducing the initial perturbation size (at 24 hours) in different regions. The area that is associated with the largest drop in final perturbation amplitude while reducing initial amplitudes is the region where the largest sensitivity is found. When compared to traditional adjoint sensitivity calculations, this technique, beyond being very cheap, has the advantage of working in the space of realistic nonlinear ensemble perturbations. In the second technique, a localized perturbation in the critical forecast area at 72 hours lead time is integrated backward in time using a linear tangent model. Results from the two independent methods closely overlap.

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THE WELS-SYSTEM: AN UNCONVENTIONAL APPROACH TO WEATHER PREDICTION

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Within the scope of a research project, the American WELS-weather prediction scheme was transferred to Central Europe. This system is PC-based and currently in real-time and operational use in parts of the United States, chiefly in support of winter highway maintenance operations. In Austria, it is at the moment being tested by various institutions such as the Viennese winter road service, the aviation service and the Institute of Meteorology (University of Vienna).

The system rests upon the concepts of hybrid modeling: An independent, grid-based mesoscale forecast model, integrating the full set of prognostic equations, delivers a 24 hour-prediction which can be manipulated and enriched by means of a Graphical User Interface (GUI), a user-interactive, graphics-based post-processing tool. The latter rests upon concepts related to artificial intelligence and includes, apart from numerous terrain-visualization facilities, the opportunity of adjusting the output of the prediction model; locally-generated observations can be incorporated into the forecasting process. The utilization of the forecast-manipulation facilities is particularly helpful if the prediction seems to be off-track; the time-consuming rerun of the entire forecast model can be avoided. If at a certain moment the current local temperature is for example discovered to be lower than forecast by the model, the prediction from that time up to the end of the forecast period can easily be adjusted in order to be in agreement with this latest measurement.

IMPROVEMENT OF THE FRENCH SST ANALYSIS WITH SSM/I SEA-ICE CONCENTRATION DATA

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The purpose of this study is to produce a more accurate sea surface temperature field over the polar oceans by using SSM/I sea-ice concentration data, in order to improve the quality of the surface fluxes computed by the French forecast system in these areas.

The method used to extract the information from the near real time global satellite sea-ice concentration data set and to make it available for the analysis scheme will be explained.

The next step is the nudging of this sea-ice cover information with the analysed SST field to obtain the final improved field used by the subsequent forecast.

Differences between the current operational SST analysis and the new SST field will be shown.

SENSITIVITY EXPERIMENT USING DIABATIC ADJOINTS OF THE SPECTRAL HIRLAM

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The adjoints of the spectral HIgh Resolution Limited Area Model (HIRLAM) have recently been developed, as a component of the forthcoming HIRLAM 4-dimensional variational data assimilation system (4DVAR). The adjoints, which include large scale precipitation and planetary boundary layer physics, are applied for a continuous data assimilation period to test the sensitivity of short-range forecast errors to initial model conditions. Results are compared to parallel experiments using only adiabatic adjoints (Gustafsson and Huang, 1996, Tellus, 48A, 501-517), in order to examine the ability of the 4DVAR system with diabatic adjoints in improving the assimilation of initial (especially the moisture) fields.

OA17 Glaciology of the Atlantic sector of Antarctica

Convener: Miller, H.
Co-Conveners: Rott, H.; Wagenbach, D.

Sponsorship: ICSI/IAHS (International Commission for Snow and Ice of IAHS)

VARIABILITY IN THE DYNAMICS OF THE BRUNT ICE SHELF SINCE 1956

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Since 1956 there has been a British station, Halley or Halley Bay, on the Brunt Ice Shelf (75: S, 25: W) on the eastern coast of the Weddell Sea. Extensive studies of the glaciology of the ice shelf were conducted until the early 1970s. A new glaciological study was started in 1987 to assist in choosing the site for the fifth Halley station. This programme was expanded in 1992 when an Applied Glaciologist was appointed to study the Brunt Ice Shelf and its effects on the station. These effects include small scale snow movement and accumulation and also the long term stability of the ice shelf. The dynamics of the ice shelf were studied primarily by the use of strain rosettes. Each summer from 1992/93 until 1995/96, over 20 rosettes were surveyed with a theodolite to measure the surface strain rate. The velocity at each site was determined from annual positions measured using Transit or GPS satellites. In addition, the movement of Halley station was measured continuously using Transit. The velocities and strain rates observed in the recent and earlier studies were examined for variability over decadal, annual and seasonal time-scales.

STABLE ISOTOPE AND CHEMICAL CONTENTS OF NEAR SURFACE FIRN FROM NEUMAYER BASE TOWARDS DRONNING MAUD LAND, ANTARCTICA

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Since the foundation of the Neumayer base (GvN) in 1980 a comprehensive set of data from stake measurements, stable isotope and glaciochemical investigations on surface firn was collected. Firn was continuously sampled in the vicinity of GvN and along traverses in the years 1987, 1988 and 1996 on the Ekstroem ice shelf, in the Ritscher Highland, Heimefrontfjella and the high plateau of Dronning Maud Land (DML). The data, most of them unpublished, give an overview on the accumulation rates, the ^{2}H-, ^{18}O contents and chemical composition of the near surface snow, stable isotope-temperature relationship and information on the build up of the snow cover. The data from DML are of special interest for the selection of an ice core drilling site within EPICA. The surface firn was sampled in snow pits and by firn coring to about 10 m depth. The dating of the firn was generally done by stratigraphical means. In the high accumulation areas it is based on seasonally varying snow parameters. In low accumulation areas annual layers may be derived from non-sea-salt sulfate only. However, the dating of the firn was generally inferred from ^{3}H depth profiles. The accumulation rates range between 360 and 40 kg m^{-2} a^{-1}, the ^{18}O contents between -20‰ at the coast and -45‰ at an elevation of 3000 m a.s.l. on the plateau of DML, respectively.

FIRST RESULTS FROM ISOTOPIC AND CHEMICAL INVESTIGATIONS ON THE 182 m ICE CORE B25 FROM THE SOUTH DOME OF BERKNER ISLAND

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In early 1995 two intermediate depth ice cores were drilled on Berkner Island in a joint effort of German and British groups. The main objective of this study is to reconstruct the climate and paleo-environmental conditions for the Weddell Sea region on a time scale of approximately 1000 years. Here we present first results of the isotopic and chemical analyses (^{2}H, ^{18}O, MSA, non-sea-salt sulfate, chloride) on the B25 core drilled on Thyssenhöhe, the southern dome of Berkner Island (860 m a.s.l.). Dating of the core was achieved from ECM measurements performed in the field. The current status of the analyses is that chemical data are available for the first 40 m of the core (corresponding to the last 180 years, approximately), and ^{2}H and ^{18}O data for the first 70 m (400 years). The results will be discussed with respect to systematic vertical trends and their comparability with data sets from other drill sites in the Atlantic sector of (coastal) Antarctica.

EVALUATION OF A REGIONAL ATMOSPHERIC CLIMATE MODEL WITH IN-SITU MEASUREMENTS AT DRONNING MAUD LAND (ANTARCTICA)

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The interpretation of ice core samples requires knowledge of meteorological conditions at the drilling site. Since observations on the Antarctic continent are relatively sparse, one may attempt to use atmospheric models to provide such information. This approach might also be useful to obtain information on past climates. However, the capability of 'state of the art' atmospheric models to simulate the present-day climate of Antarctica is not well established, partly due to the lack of comprehensive field campaigns on the continent.

In the austral summer of '92-'93, extensive measurements of the boundary-layer structure and the surface energy fluxes were carried out by the IMAU at SVEA, Dronning Maud Land. A two-week period of this season is simulated with a regional atmospheric climate model (RACMO), utilizing the physical parametrisations of the ECHAM4 GCM. The employed horizontal grid of 55 km, resolves the topography and the katabatic winds in sufficient detail. ECMWF re-analyses are used to relax the prognostic variables at the lateral boundaries and to update the sea surface temperature and sea ice mask.

A detailed comparison of model results with the measurements is performed. An important result is that RACMO generates temperatures profile in the boundary layer that corresponds reasonably well to the IMAU measurements. However, the simulated water vapour content in the boundary layer is significantly overestimated. The model sensitivity to albedo parametrisations, initialisation of ice temperature profiles and surface roughness is tested.

RECONSTRUCTING A 2000 YEAR RECORD OF CHEMICAL AND CLIMATIC PARAMETERS BASED ON INTERMEDIATE-DEPTH ICE CORES DRILLED ON THE CENTRAL FILCHNER–RONNE ICE SHELF

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Two intermediate-depth ice cores, B13 and B15, were drilled in the field seasons 1989/90 and 1991/92 on the central Filchner-Ronne Ice Shelf accompanied from an extensive sampling program of shallow firn cores as well as glaciological measurements. This study deals with the meteoric ice of both cores, the upper 153 m approximately. Isotopic and chemical analyses were performed to obtain a complete picture of the vertical structure of the ice shelf. We will show, that due to the relatively fast flowing ice shelf the longitudinal distributions of chemical and isotopic properties at the surface upstream of the drilling sites are clearly reflected in the vertical profiles, particularly the strong continental effects of ^{2}H, ^{18}O and sea salt. We use a simple particle path model based on the observational data of accumulation rates, surface strain and horizontal flow velocity to de-couple spatial and temporal trends in the ice core data sets and for establishing the ice core chronologies. The resulting isotopical and chemical records, covering the last 2000 years approximately, will be discussed with respect to their proxy information on the climatic and environmental situation of the Weddell Sea region and the limitations in accurately tracing back the origin of ice in a highly dynamical ice body.

THE INFLUENCE OF THE WEDDELL SEA ON THE CHEMISTRY OF COATS LAND AND DRONNING MAUD LAND*

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Soluble chemistry and stable isotope results from a series of shallow (20m) ice cores taken on a traverse between the north and south domes of Berkner Island in 1995 are compared with two intermediate depth cores from the domes in order to assess the spatial change in the palaeoenvironmental signal of the Weddell Sea. Further comparison is made with shallow cores drilled in Coats Land, and at Halley Station. The data are used to discuss the extent of the influence of the Weddell Sea on the chemistry of precipitation in Coats Land, and predict the effect further eastwards into Dronning Maud Land.

BLUE ICE AREAS IN DRONNING MAUD LAND: A SOURCE OF ICE FOR PALEOCLIMATIC STUDIES ?

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In Dronning Maud Land many blue ice areas exist. Their occurrence is related to special micro-meteorological conditions, creating a negative surface balance of the order of 10-40 cm of water equivalent per year, mainly due to evaporation. In many cases these conditions are due to the effect of nunataks on atmospheric flow and snow drift.
A negative surface balance in a limited area creates converging trajectories in the ice-flow pattern and hence old ice appears at the surface. Especially in those blue ice areas where no melt occurs at the surface, this ice could be of use for paleoclimatic studies.
Scharffenbergbotnen in Heimefrontfjella is a blue ice area that appears to be suitable as a source for old ice. Micro-meteorological work, 14C studies on a number of shallow cores from the surface, and mass balance observations suggest that this blue ice area is stable, has no surface melt (except very close to mountain walls) and contains high-quality ice for chemical and physical analysis. Schematic ice-flow modelling suggests that the ice in Scharffenbergbotnen is of local origin and probably has a relatively simple history.
In this presentation results from this earlier work will be reviewed. Then a strategy for further study and exploitation of this blue ice area will be presented.

THE DISINTEGRATION EVENT ON NORTHERN LARSEN ICE SHELF, ANTARCTIC PENINSULA

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After a period of steady retreat two sections of the northern Larsen Ice Shelf, Antarctic Peninsula, disintegrated almost completely within a few days in early 1995. This event follows a period of atmospheric warming in this region which is believed to be close to the climatic limit for the existence of ice shelves. A detailed analysis of the disintegration event is presented, based on close time sequences of Synthetic Aperture Radar (SAR) data of the European ERS-1 satellite. This analysis is complemented by field observations on surface mass balance and ice motion which have been carried out 2 months previously. The ice shelf section at Prince Gustav Channel (at about 64°S, between the Antarctic Peninsula and James Ross Island), and the section between Sobral Peninsula (64.5°S) and Seal Nunataks (65°S) disappeared almost completely. The rapidity of the collapse and the observed features indicate the importance of fracture dynamics. At the same time a major calving event was observed between Seal Nunataks and Jason Peninsula (66°S). Satellite and ground-based observations in 1996 indicate that the retreat of this section may accelerate.

DATING OF SIRIUS GROUP MORAINE AT MOUNT FLEMING, DRY VALLEYS, ANTARCTICA, WITH COSMOGENIC ^{21}NE

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Analyses of in-situ produced cosmogenic noble gases and radionuclides in boulders from a Sirius Group moraine at Mt. Fleming, Southern Victoria Land, Antarctica, (Bruno et al. [1] and Ivy-Ochs et al. [2]) are completed by studies of additional samples of this region. These data offer the first direct age determination of such moraines by surface exposure dating. The samples with the highest ^{21}Ne concentrations yield a minimum exposure-age of ~7 Ma. These ages are among the highest exposure ages measured on terrestrial surfaces so far. The moraine at Mount Fleming had thus been formed by late Miocene at the latest and therefore contradicts the hypothesis of a collapse of the East Antarctic ice sheet in the Pliocene, which postulates a formation of the Sirius Group at Mt. Fleming 3 - 2.5 Ma ago [3]. The preservation of these surfaces indicates a continous cold desert in the Dry Valleys and strongly supports the view of a stable East Antarctic ice sheet [4] with obvious implications also on the Atlantic sector of the continent.

[1] L.A. Bruno et al, Earth and Planetary Sciences Letters, submitted. [2] S.Ivy-Ochs et. al., Geology 23, 1007-1010, 1995. [3] P.N. Webb et al., Geology, 12, 287-291, 1984. [4] D.E. Sudgen et al., Nature 376, 412-414, 1995.

OA18 Physically-based snow models and their links to GCMs

Convener: Brun, E.

Sponsorship: IAHS/ICSI (IAHS International Commission on Snow and Ice)

GCM SNOW SIMULATIONS: INTERANNUAL VARIABILITY AND SENSITIVITY TO INITIAL CONDITIONS

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The Center for Ocean-Land-Atmosphere Studies general circulation model has been integrated using observed sea surface temperatures for the period 1982-1992. Model simulated snow, as well as winds, precipitation and temperature are analyzed and compared to observations. The ability of the model to reproduce observed precipitation is shown to be dependent on the convection scheme used.

Sensitivity of the large scale circulation to initial enhanced/reduced snow anomalies is examined in several short integrations, starting in the spring and ending at the end of the summer season. Various regions of Eurasia are chosen for the reduced/enhanced snow anomalies. It is shown that subsequent circulation is critically sensitive to the location and extent of anomalies.

While sea surface temperature and soil moisture have been shown to be important determinants of atmospheric predictability on seasonal and longer time scales, the activity of snow variability in winter and spring represents a possibly complementary effect.

THE COUPLING OF A MULTI-LAYERED SNOW MODEL WITH A GCM

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In order to improve the representation of snow cover in climate simulations, a multi-layered snow model, including most physical processes occuring inside a snowpack, has been coupled to a GCM . The snow model, called Crocus, simulates the evolution of snowpack layering which allows a realistic calculation of snow albedo as a function of the type and size of the crystals of the surface layer. The coupling scheme is based on a synchronous run of the GCM and of the snow model with an exchange of the surface fluxes at every time step. It was tested in a 5 year run at a T42 resolution. The impact on the atmosphere was important over most snow covered regions and the snowpacks simulated in the different regions present a layering which is realistic and very variable in connection with the climate. The simulated snow cover compares satisfactorily with the present snow climatology.

SNOW-COVER STUDIES IN GREENLAND: SNOW PITS OBSERVATIONS AND NUMERICAL MODELLING

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13 snow pits were sampled during May and June 1996, along 3 traverses in Greenland from Summit (72°20'N, 38°45'W) to the North (250km), East (250km) and South-west (350km) in order to measure the main characteristics of the snow-cover: temperature profile, density profile, stratigraphy, snow grain type and snow grain size. Numerical simulations of the snow-cover have been performed for each site with the snow model CROCUS. The meteorological data needed to force the snow-model have been compiled from the European Center for Medium Range Weather Forecasts (ECMWF) archives and from Automatic Weather Stations observations. Results of snow cover simulations will be presented and compared to the snow pits observations.

SNOW MODELLING IN THE HADLEY CENTRE GCM

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The Hadley Centre GCM, in common with most other GCMs, currently uses very simple representations of snowpack processes (reviewed here), but physically-based parametrizations are being adopted which offer more realistic representations of interactions between snowpacks and the atmosphere. Improved representations of heterogeneous snow cover, interactions between snow cover and vegetation canopies, the impact of aging on snow albedos, and sublimation from blowing snow will be discussed. Comparisons will be shown between parametrizations, observations and detailed process models.

AN ENERGY BALANCE MODEL OF SNOW EVOLUTION

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This study describes a snowmelt model based on a physical heat balance method. It is an adaptation of the one-layer model proposed by Kondo and Yamazaki (1990). As this last one it takes into account both the heat balance at the snow surface and that of the entire snow cover, and predicts both the snow surface temperature and freezing depth. The model predicts also the evolution of the snow's liquid water content, dealing with its refreezing amongst other processes . The energetic equation is formulated by means of two energetic variables: the 'Water Content' and the 'Termic Content'. Percolation is considered as an independent process, and with a parameterization that is function only of the snow's density and liquid content. The model has been validated through field measurememts obtained at the instrumented site of Col de Porte of the 'Centre d'Etudes de la Neige (CEN-Meteo France)' corresponding to the winter seasons of 1988-89, 93-94 and 94-95. The behaviour of the model is also studied using a parameterization of the albedo and different integration time-steps.

RADIATION-BASED SNOWMELT MODEL FOR MOUNTAIN TERRAIN.

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An energy-balance model is developed to estimate the net radiation and the transfer of energy between the atmosphere and a complex snow-covered terrain. The model was applied for simulation of snowmelt within small cathments in Tien-Shan and Caucases mountains, using GIS. Each of energy balance variables is modelled at each point on a rectangular grid corresponding to a digital elevation model. Characteristics of radiation receipt are simulated, taking into account the terrain enclosure and the radiation slope factor , the last being obtained experimentally as a function of slope, exposure, horizon information and time. Air temperature, humidity and wind variations over terrain are specified on input to the model by an empirical functions. Field studies of albedo, snow depth, snow-water eguivalent and snow surface temperature provide data for calibrating and testing the model, where snowmelt is determined from energy balance equation by a residual procedure. Well-defined relationship between net radiation, albedo and snowmelting was shown.

DEVELOPMENT OF THE SEASONAL SNOW COVER MODEL FOR ENERGY BALANCE CLIMATE MODELS AND GCM

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Based on dimensional analysis and theory of dynamical similarity the connection between meteorological values and position of the boundary of seasonal snow cover (BSSC) was developed. It was found that BSSC exists in the regions where e (pressure of the water vapour) and t (temperature of the air near surface, 0C) satisfy the criterion $(0.25e - 0.08t) = 1.5$, $t < 1$ 0C . Parameters were determined based on observed data over Europe and Asian continent. We assume that prognostic snowmass is determined from traditional budget equations only within the area which are bounded by BSSC. This approach have used in GCM of the Moscow State University .

AN IMPROVED SNOW PHYSICS IN THE ECHAM MODEL

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A physically based model of a snow cover, which has successfully been tested in stand-alone-experiments, was implemented into the atmospheric climate model ECHAM4. The multi-layered snow model, which uses a variable number of layers, resolves the snow internal processes. The model also considers a partial snow coverage of the grid-cells and an albedo masking effect by vegetation. Simulation results of the coupled model will be shown and compared with the simulated snow properties using the standard ECHAM4 snow parameterization.

FORTHCOMING CHANGES OF SLUSHFLOW PHENOMENA DUE TO GLOBAL WARMING.

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Slushflows are one of nature hazards. Their origin depends on prosesses of snow cover destruction. Slushflow phenomena possible changes in Northern Hemisphere are described. The version of climatic changes of GCM GFDL was used. The original methodology, worked out of the Geography Faculty of MSU, at its Scientific Research Laboratory of Snow Avalanches and Mudflows was applied. This method is based on the relationships between the climatic parameters and the main indices of slushflow phenomena (such as distribution, regime and activity). These relationships revealed by longtime detailed investigations the slushflow phenomena on the territory of FSU. It is notable that the area of slushflow distribution in FSU is by 1/2 of total area of its distribution in the World. The following schemes are given: 1). The changes of the area of slushflow existence; 2). The changes of main climatic factors, responsible for slushflow activity (the amount of snow, amount of precipitation during snowmelting, speed of air temperature increasing in spring; the amount of forest vegetation); 3). The changes of slushflow activity. The main results of estimation are following: 1. The areas of slushflow distribution will decrease by about 40%. 2. The slushflow activity will decrease on the greater part of territory of America and Europe. 3. The slushflow activity will increase in some large regions of NE Asia. 4. The changes of slushflow activity will be insignificant approximately on 1/3 areas of its modern existence. 5. The time of maximum slushflow risk period will be one month earlier to the beginning of spring over most part of territory.

OA19 Snow and ice chemistry of alpine and polar regions

Convener: Kuhn, M.
Co-Convener: Delmas, R.J.

Sponsorship: ICSI/IAHS (International Commission for Snow and Ice of IAHS)

VERTICAL PROFILES OF THE GROSS BETA AND PB-210 ACTIVITY IN AN ICE CORE SAMPLED AT COLLE DEL LYS

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Profiles of gross beta and Pb-210 activity in glaciers can be used to evaluate the pattern of the annual net accumulation rate. Evaluations were performed on about 60 chip samples produced during the sampling of a more than 80 m long core at Colle del Lys in summer 1996. 400 ml of melted ice was acidified with HCl and evaporated to 5 ml. Concentrated samples were added with 15 ml of scintillation cocktail and measured with a low-background liquid scintillation counter. An alpha-beta separation was performed in order to obtain simultaneously gross beta and Po-210 (daughter of Pb-210 in secular equilibrium) activity.

TRACE ELEMENTS IN ALPINE SNOW AND ICE

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After the emission of aerosol-borne trace elements into the atmosphere, these are transported from the sources to even the highest alpine sites by strong convective processes. There they are deposited on e.g. the glaciers mainly during precipitation events. Thus, measurements of trace element concentrations in snow and ice of high-alpine glaciers can be used to determine differences of air composition between the present and past. In order to study trace element concentrations and isotopic ratios in snow and ice from alpine glaciers, shallow firn and deep ice cores were drilled and snow pit samples were collected on Aletschgletscher (Jungfraujoch, 3450 m a.s.l.), on Grenzgletscher, and on Colle Gnifetti (Monte Rosa massif, 4200 and 4450 m a.s.l.). After sample preparation under clean room conditions trace elements, e.g. Al, As, Cd, Cu, Pb, V, and Zn, were analysed by double focusing inductively coupled plasma mass spectrometry (HR-ICP-MS). This technique allows to run multielement methods with detection limits in the pg/g range and the determination of the lead isotopic composition with a total sample amount of 5g, only. Concentrations of most trace elements have increased during the last 200 years, reflecting the dramatic perturbation of snow chemistry by anthropogenic impact. Lead is particularly suited to study the influence of human's activities, since its isotopic ratios can be used to identify the sources. Our data indicate, that lead emissions from automobiles still contribute to an equal amount to the concentrations in modern snow than other anthropogenic sources (e.g. waste incinerators, industries).

CHARACTERISATION OF PARTICULATE MATERIAL IN THE RECENT SNOW AT SUMMIT (GREENLAND)

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Particles characterisation by Analytical Transmission Electron Microscopy was lead to contribute to the study of the source regions influencing Central Greenland. Samples from a 4 m depth snowpit at Summit (altitude 3270 m) covering the period between summer 86 and summer 91 were melted and filtered before analysis. Particles recovered on a Nuclepore filter were analysed by X Ray Fluorescence Spectrometry and indicate a systematic strong peak during spring for crustal elements. Four snowpit samples were selected according to the aluminium profile, which is a global tracer of the crustal dust. In each sample, we determined first the number size distribution in order to distinguish a local source. Then, the proportion of some mineralogical species, obtained by ATEM was compared to the mineralogy of the potential regions of dust inputs on the Greenland ice sheet.

THE HISTORICAL RECORD OF AEROSOL RELATED SPECIES IN ICE CORES FROM THE ALPS

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Alpine glaciers are very well suited for the reconstruction of the history of atmospheric concentrations since they are surrounded by the highly populated and industrialised areas in Europe and this proximity to the emission sources facilitates the interpretation of the observed records. Furthermore, historical meteorological and air quality measurements exist, which can be used to calibrate the paleo(climatic) data.
The potential of alpine glaciers for the reconstruction of historical atmospheric concentrations of aerosol related species will be demonstrated by discussing records from two ice cores (from Colle Gnifetti, Monte Rosa massif, 4450 m a.s.l., and from Fiescherhorn, Bernese Alps, 3850 m a.s.l., Switzerland). These two glacier sites are characterised by accumulation rates differing by an order of magnitude and, thus, allow to deduce information on different time scales. On the one hand, by looking at the period of industrialisation, exponential increases of the concentrations were observed for the species ammonium (1870-1960), nitrate (1930-1965), and sulphate (1870-1965), and the factors of increase amounted to 2.2±0.4, 2.3±0.3, and 5.8±0.9, respectively, and were in good agreement with estimates of anthropogenic emissions of SO_2 and NH_3 in Europe. On the other hand, the seasonally resolved sulphate signal over the last 30 years allowed the calibration of the ice core record by actually measured atmospheric sulphate concentrations from an air quality programme.

NATURAL AND ANTHROPOGENIC INFLUENCE RECORDED IN A COLLE DEL LYS NEW ICE CORE (ITALIAN ALPS).

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A new 80 m ice core, has been drilled at 4250 m a.s.l. on the Colle del Lys, Monte Rosa, Italian Alps. The density profile measured during the drilling operations shows the close-off depth at about 40 m. The ECM profile has been whose measured on the first 60 m and provided a record of the chemical acidic load, showing a decreasing trend in the last two decades Major conductivity spikes may be related to high acidic anthropogenic events. The 1977 Saharan dust deposition event has been clearly identified at 48 m depth, and used, with 1963 tritium thermonuclear bomb tests maximum, to set-up a depth/age curve spanning the last 40 years. Visible horizons as ice lenses and dust layers have been used to identify the seasonal stratigraphy and to evaluate the annual accumulation rate (1.7 kg m-2 y-1). The high accumulation rate at Colle del Lys permit to evaluate the seasonal variations of natural and anthropogenic influences on the Central Alps.

MAJOR ION CHARGE SPATIAL VARIABILITY ON WINTER SNOW DEPOSITIONS AT HIGH ELEVATION SITES: THE 1995 CAMPAIGN ON NORTH-EASTERN ITALIAN ALPINE GLACIERS.

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Following the experience of the EUROTRA/ALPTRAC Project, an experiment to assess the spatial variability of the ion charge of the winter snow depositions, has been carried out. The two sites interested by the experiment are the Careser Glacier (Ortles-Cevedale Mountain Group) and Mandrone Glacier (Adamello Mountain Group), both situated on north-eastern Alpine Glaciers at elevations ranging over 3000 m, at a distance of about 5 km, facing each other. Both the sites have been equipped with meteorological stations with direct recording of snow depth and temperature, air temperature and relative humidity, incident and reflected solar radiation fluxes, wind velocity and direction, air pressure.
The snow sampling has been performed at the beginning of March and covered the whole snow cover thickness, with a sampling resolution of 10 cm.
The snowcover evolutions recorded by the two stations show a noticeable coherence, as for the distribution of the ionic concentrations of the deposition events with lower ionic charge, which can represent the background situation. The total ion charge gives a clear excess for the Adamello samples (the southernmost site), due to the scavenging effect on the air mass along the trajectories carrying to the Careser.

ICE CORE RECORD OF CO VARIATIONS DURING THE LAST TWO MILLENNIA: ATMOSPHERIC IMPLICATIONS AND CHEMICAL INTERACTIONS WITHIN THE GREENLAND ICE.

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In order to study in detail the pre-industrial CO level during the last two millennia and its temporal variations, ice cores from Greenland (Eurocore, GRIP) and Antarctica (Vostok) have been analysed. The Antarctic results suggest that atmospheric CO concentrations did not change greatly over Antarctica during the last two millennia (45-55 ppbv). Between 1600 and 1800 A.D., CO concentrations obtained in the Greenland ice are also very close to those previously reported for the 1800-1850 A.D. period (Haan et al., 1996). They indicate a mean pre-industrial Greenland value of about 90 ppbv. By contrast, the oldest part of the Greenland CO profile exhibits high CO levels (100-180 ppbv) characterised by a large variability. This part of the record likely not reflect the true atmospheric CO concentrations. Several processes which could have altered the atmospheric CO signal either before or after its trapping in the ice are discussed. Because there are similarities between the Greenland CO and CO_2 concentration profiles for the 1000-1600 A.D. period, mechanisms involved in both cases could be at least partly the same.

THE SNOW COVER AT FRANZ-JOSEF-LAND: CONCENTRATION OF NATURAL AND ANTHROPOGENIC TRACE SUBSTANCES IN THE SNOW PACK AT GLACIERS OF THE ARCHIPELAGO

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An increasing influence of anthropogenic pollutants in arctic areas appeared from several investigations in the Canadian Arctic and in Greenland. In the summer of 1995 the chemical composition of the snow cover at glaciers of Franz-Josef-Land (FJL) was investigated for the first time. Ion concentrations showed a pronounced seasonal variability being up to 10 times higher in late spring and summer than in winter. The high regional differences of ion concentrations and ionic loads may be attributed to the strong influence of wind on the accumulation and deposition of snow there. Snow at glaciers in FJL differed considerably from snow at alpine glaciers both in mean ion concentrations and in respect to the relative contribution of major ions to the ion sum. This is in agreement with observations in other parts of the Arctic where the influence is most pronounced during winter and spring favored by large-scale circulation patterns, atmospheric stability and low scavenging ratios causing an enrichment of anthropogenic trace substances from the Eurasian continent in the arctic atmosphere during this part of the year.

SCAVENGING OF AEROSOL RELATED CHEMICAL SPECIES BY SNOW

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The scavenging of atmospheric trace species by snow and the subsequent removal by precipitation is the most important cleansing mechanism of the earth atmosphere. A variety of processes are involved in and below a cloud. The most complex scavenging situation occurs in mixed phase clouds, i.e. clouds containing ice crystals, which is the type of cloud that typically produces precipitation in moderate climates. The first step of the scavenging process is the activation of aerosol particles to cloud droplets. Experiments conducted at the Jungfraujoch showed that this activation results in an almost complete transfer of the aerosol related species into the cloud droplets. After ice nucleation, ice crystals grow by water vapour deposition at the expense of the supercooled cloud droplets and/or by riming. Impurities are mainly incorporated into the ice phase by riming, while pure diffusional growth leads to very clean crystals. The degree of riming depends on a variety of parameters, such as cloud droplet size, snow crystal size and snow crystal settling velocity. The rimed mass fraction can be determined by taking Formvar replica of the ice crystals followed by microscopic examination. Rather good agreement was found between the measured concentration of a certain trace species in the snow and the concentration calculated from the rimed mass fraction and the respective concentration in cloud water. However, the total mass transfer from the atmosphere into the snow was rather low (15 to 50%, depending on the chemical species).

THE DIFFUSION OF NITRIC ACID INTO ICE

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Eight single crystals of ice without detectable grain boundaries and four polycrystalline samples, about 80 mm on a side, were frozen to glass plates and cut to about 5 mm thickness with a band saw. The samples were flattened using a large microtome. Four of the single crystals samples were oriented parallel to the basal plane and four to a prism face. Two samples each of the same crystal orientation were subject to a 280 SCCM flow of 80 ppmV HNO_3 in dry artificial air and a similar set in air that had been humidified to suppress sample ablation for 72 to 100 hours. Thirty μm sections were removed using the microtome for analysis of NO_3^-. The diffusion coefficients calculated from these data are (cm^2 s):

Polycrystal	Prism	Basal	Average
8.8E-12	1.5E-11	1.9E-11	1.5E-11

Systematic errors may have led to an overestimate of the diffusion coefficient. The values indicate that diffusion of HNO_3 into ice may be important for multiyear ice.

SEASONAL PATTERN AND FRACTIONATING EFFECTS OF SULPHUR CYCLE COMPOUNDS IN ANTARCTIC SNOW.

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The $nssSO_4^{2-}$ - MSA relationship was studied in snow from Antarctic coastal sites (Northern Victoria Land). Using Na as sea spray tracer and MSA as biogenic marine indicator, it was possible to evaluate the contribution of the station altitude, and therefore of the aerosol particle size, on fractionating effects. As the altitude increases, and the aerosol size decreases, the $nssSO_4^{2-}$/MSA ratio increases from 2 (700 m a.s.l.) to 5 (3000 m a.s.l.). The $nssSO_4^{2-}$-MSA correlation, very good at the lowest station (R>0.970, slope≈2.1), decreases with altitude. The $nssSO_4^{2-}$/MSA ratio increases as the MSA concentration decreases in all the stations, pointing out a non-DMS source for $nssSO_4^{2-}$ (volcanic, crustal or long range transport effects) or contributes of secondary marine aerosol from lower latitudes (higher $nssSO_4^{2-}$/MSA ratio). The seasonal behavior of these compounds, observed in high resolution samples from firn cores and snowpits, reflects the seasonal aerosol inputs of biogenic DMS. A linear combination of H_2O_2, $nssSO_4^{2-}$ and MSA concentr./depth profiles was used for annual snow layer identification (chemical dating).

CHEMICAL COMPOSITION OF SYNGENETIC ICE-WEDGE COMPLEXES OF SIBERIAN PERMAFROST.

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Distribution of chemical elements in Late Pleistocene, Holocene and modern syngenetic ice wedges and in their host sediments has been studied in different regions of Siberia (Western Siberia, Yakutia, Chukotka) by analyzing of more than 2000 samples. It is established that total contents of bicarbonate, chloride, sulfate, sodium, potassium, magnesium, calcium and iron concentration in more than 80% relict and modern syngenetic ice wedges is 30-90 mg/l (fresh and extra fresh content, close to ionic concentration in precipitation), rare - not more than 17-18% - 100-200 mg/l and less than 3% - more than 200 mg/l (in extreme: 1,2 g/l - at Island Belyi (Western Siberia), 1,3 g/l - at Krestovka River, 2,9 g/l at Oval'noe Lake and 3 g/l - in the Chukoch'ya River mouth (Yakutia), but these examples are unique). Usually ice wedges are fresh independently of origin and salinity of host sediments and of distance from Arctic Ocean coast. The chemical elements enter the permafrost phase (in ice-wedge ice) in the same proportions in which they occur in precipitation (or in snow cover). Meteoric water is the main source for ice-wedge ice, it penetrates into freezing cracks during late winter snow melting (in permafrost zone it is April, May or Early June), when thawed water flows under snow cover.

EXTRACELLULAR FERMENT ACTIVITY AS INDICATOR OF ICES ORIGIN IN SYNGENETIC PERMAFROST THICKNESS NEAR SEYAHA SETTLEMENT IN YAMAL PENINSULA (WESTERN SIBERIA)

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Different types of syngenetic ices in cross section of the Seyaha permafrost complex were analyzed for proteolytic (PA) and amylolytic (AA) activity using spectrophotometer (SF-46). Ionic chemical composition (CC) was also determined. Radiocarbon dating used to establish the age of ices. Different types of ices shown different results: ice-wedges dated 13-20 ka BP at the top of complex: PA - 100-200 fermentative unit (per litre), AA - 100-260 f.u., CC - 110-137 mg/l and dated 25-30 ka BP: PA - 58-76 f.u., AA - 128-160 f.u., CC - 42-80 mg/l; ice-wedges dated 10-6 ka BP in syngenetic peat bog: PA - 46-76 f.u., AA - 26-62 f.u., CC - 25 - 70 mg/l, this fixes the facial changes during formation of ice-wedge located at the top and near bottom of cross section and different influence of Ob lagoon on ice-wedge composition features. All Late Pleistocene textureforming ices at the top and near bottom of the complex are similar to their fermentative activity: PA - 150-520 f.u., AA - 26-234 f.u. Holocene textureforming ice in syngenetic peat bog is another: PA - 26-62 f.u., AA - 122-140 f.u. Analyses of fermentative activity are a new powerful tools for precision palaeogeocryological reconstructions in polar regions.

CHEMISTRY OF UPPER FIRN LAYERS AT VOSTOK STATION, ANTARCTICA

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For very low accumulation Antarctic sites (A< 5 $g^{-1}cm^{-2}a^{-1}$), preliminary studies have shown that, in shallowest layers, several processes do modify the initial chemical composition of the deposited snow. A 32 m firn core recovered in Dec. 1991 at Vostok Station (A ~ 2.0 $g^{-1}cm^{-2}a^{-1}$) and covering the last 8 centuries has been carefully analysed for major ions. 217 samples from specific depth levels were measured by ion chromatography. It is found that concentration depth profiles are markedly different for aerosol derived ions (e.g. SO_4, Na, ...) and for ions linked (or possibly linked) to acid gaseous species like Cl (HCl), NO_3 (HNO_3), F (HF) etc...For the latters, a dramatic decrease of concentration is observed from the surface in the upper 2-4 meters. The data suggest that initial chemical concentrations are progressively altered in situ during the slow transformation of snow into firn. Comparing chemical studies at different polar sites, we tentatively propose physico-chemical processes explaining the measurements. The consequences of such phenomena for the interpretation of the deep Vostok ice core -and more generally for central antarctic records- are discussed.

PROCESSES CONTROLLING AIR-SNOW TRANSFER OF AEROSOL SPECIES AT HALLEY, ANTARCTICA

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In order to learn how to invert atmospheric concentrations from ice core chemical data, it will be necessary to study the air-snow transfer processes under a range of conditions. Until now, there are very few data from Antarctica. We will present a dataset of aerosol, surface snow, and accumulated snow collected year-round at Halley station, Antarctica (75°35'S, 26°19'W). At this site with relatively high snow accumulation, we find that fog deposition and dry deposition cannot play a major part in the flux to the snow surface. Wet deposition in snowfall dominates, and is the process requiring further study, though the important role of drifting snow is hard to quantify at this site. We consider the timescales of events that are in fact recorded in the snow. Finally, we consider over what geographical area wet deposition remains the key process.

OA20/ST20 Storm track and cyclone variability

Convener: Ulbrich, U.
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MECHANISMS FOR MID-LATITUDE CYCLONE DEVELOPMENT

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The work presented explores the dependence of perturbation structure, location and scale on the linear evolution in a series of initial value problem experiments. An Eady model set-up is used to investigate the simplest quasi-geostrophic behaviour. Perturbations which are confined both vertically and horizontally in streamfunction yield the greatest kinetic energy growth rates. Growth rates in excess of the fastest growing normal mode are achieved without any phase tilt with height. This can be explained using PV ideas. The initial configuration, a primary PV anomaly region flanked above and below by PV of the opposite sign, is dismantled by the sheared basic flow. The resulting unshielding of the primary PV induces flow over a larger part of the domain. Experiments performed using a primitive equation model demonstrate similar behaviour, but in this case upward propagation of Rossby waves in the interior provides a significant mechanism for growth over the first day or so. The perturbation scale associated with the upward propagation of wave activity is investigated in zonally symmetric and asymmetry basic flows. If boundaries are involved from the beginning this large transient growth is suppressed. However at later times they are vital for the continuing near normal mode growth. The perturbations and evolution share properties of optimal modes and singular vectors. Here, the emphasis is on understanding the physical basis of these properties.

ON THE MODIFICATION OF EXTREME WIND SPEEDS AT THE BALTIC COAST OF MECKLENBURG-VORPOMMERN

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In the scope of the climate research program of the Baltic Coast of Mecklenburg-Vorpommern the sites of Wustrow and Warnemünde were examined with respect to extreme winds. The time series were corrected for the local effects to get a long and homogenous time serie from 1880 to 1993. The time series of the 1, 10 and 50 % percentiles derived from five years distributions of the long time serie show no change in the storm frequency and the average wind speed in the past 100 years. To get some information about the modification of the baroclinicity the annual thermal wind speed between the 700 and the 850 hPa-level of Greifswald was determined. The investigation shows no significant change of the thermal wind speed since 1949. These two different investigations give no indications for a change in the frequency of extreme wind speeds in the past.

Interpretation of Eulerian storm track diagnostics

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The intensity of storm tracks is commonly measured in terms of Eulerian diagnostics such as the eddy kinetic energy which is associated with cyclones moving with a certain phase speed. This phase speed is not only dependent on the cyclone itself but also on the background flow in which the cyclone is embedded. Hence, Eulerian storm track diagnostics such as eddy kinetic energy of the high pass filtered fields do not only pick up the variability in eddy activity or the variability in the structure of cyclones, but also the temporal and spatial changes in the backgrouud flow. Especially in areas of weak zonal flow (over the continents) and in times of low wind speeds (blocking) this impact of the background flow may be significant. A method to eliminate the dependence of the Eulerian storm track diagnostics on the background flow, based on Doppler shifting of the eddy activity, is proposed and tested.

STORM TRACK AND LOW FREQUENCY VARIABILITY SVD ANALYSIS

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Many authors have put in evidence a link between the slowly varying component of the circulation, mainly related to blocking events, and storm tracks activity; nevertheless the relationships between the low- and high-frequency components of the atmospheric circulation need further investigations.
Here we use a Singular Value Decomposition technique (SVD) to correlate storm tracks, defined as the 2.5-6 day bandpass filtered component of the 500-hPa height fields, with monthly mean wintertime fields.
The analysis has been performed on an observed dataset starting from January 1979 to December 1988 (ECMWF analyses) and then applied to an ensemble of AGCM simulations forced with prescribed SST for the same 10-years period. The SVD analysis was performed in two separate regions, the Euro-Atlantic and the Pacific sectors, trying to verify the existence of different time-scales of atmospheric variability in the two regions. SVD analyses were applied both to monthly mean and seasonal mean time series in order to distinguish the interannual and intraseasonal variability.
Preliminary results show a strong correlation between storm tracks and sea level pressure in both sectors for observed and simulated data; it is also evident the presence of the teleconnection pattern in the correlation maps. The Atlantic observed variability appears slightly more pronounced than the Pacific one; while this behaviour is not evident in the simulated data.

DIABATIC HEATING IN STORMTRACK EDDIES OF PRESENT DAY AND 2*CO_2-FORCED CLIMATE

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Different diabatic processes are affecting transient baroclinic disturbances in mid-latitudes. It is investigated if and how this influence changes due to increasing CO_2-forcing for boreal winter. Three dimensional distributions of heating rates are taken from the parameterized diabatic processes in the ECHAM4-GCM. Model runs for present day climate and a greenhouse scenario are considered. The direct effects of different diabatic heating processes on the mid-latitude transient baroclinic disturbances are estimated by local contributions to the generation of their available potential energy (GE_{TR}).
Large-scale latent heat release (LLH) in middle troposphere is the dominant process with respect to the tropospheric production of GE_{TR} in the mid-latitudes. In the Pacific maxima of local contributions of GE_{TR} due to LLH are generally located upstream of largest stormtrack activity. Both quantities are correlated with each other. For the Atlantic no such clear relationship is found.
In the scenario run the Pacific stormtrack maximum and the associated GE_{TR} contributions are shifted northward. The moderate increase of mean stormtrack intensity is not associated with significant changes of GE_{TR}. Over the Atlantic, the most prominent signal is a downstream extension of the stormtrack into Europe. It is accompanied with increased local contributions of GE_{TR} in the central North Atlantic. The effect over this ocean basin is associated with a local enhancement of mean meridional water vapour advection from the subtropics.

CONTROL MECHANISMS AND SEASONAL VARIATIONS OF STORM TRACKS IN MARS' ATMOSPHERE

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Midlatitude synoptic scale low-pressure cyclones and their accompanying frontal systems tend to develop, travel eastward, and decay preferentially within certain geographic regions commonly designated as storm tracks or storm zones. Like Earth, Mars is a rapidly rotating solid planet with a seasonally varying shallow atmosphere where traveling weather systems also occur. Further, both planets exhibit large-scale orography and, in a broadly defined context, continentality. Numerical simulations with a Mars global atmospheric circulation model suggest that northern storm zones can exist in early autumn through late spring. Band-pass filtered transient eddy variances/covariances become quite localized during winter and are strongest during early spring. Following weakening baroclinicity during the seasonal transition, the eddy activity rapidly weakens and the associated storm 'belt' shifts into high latitudes. Compared to Earth, where land-ocean thermal contrasts appear vital in the maintenance of storm zones, Mars' continental-scale orography can effectively localize its synoptic-scale weather activity. Experiments using only zonally symmetric topography indicate not only a zonally uniform storm belt but also the transient eddy activity becomes very enhanced and is significantly dominated by low-frequency modes. Given basic similarities between the two planets, detection and characterization of storm zones on Mars should provide insight into fundamental underlying mechanisms, particularly regarding the importance of surface mechanical and thermal effects.

A review of storm track mechanisms

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The term storm-track suggests that mid-latitude cyclones tend to be initiated in a certain region, move and grow long a limited quasi-longitudinal corridor, and decay in a certain region. The mechanisms that have been discussed for these various aspects of behaviour and the feedback of the cyclones onto the existence of the storm-track will be discussed. Implications for the variability of the N. Atlantic storm-track and possible changes in it due to anthropogenic effects will be drawn.

UNDERSTANDING MID-LATITUDE STORM-TRACKS IN A GENERAL CIRCULATION MODEL: REGRESSION ANALYSES AND BAROCLINIC LIFECYCLES

M. Kageyama and P. J. Valdes (Department of Meteorology, University of Reading, United-Kingdom)

To investigate the northern hemisphere winter storm-track representation in General Circulation Models (GCMs), we analysed some UGAMP GCM simulations in the following way: we first determined the characteristics (mainly wavenumber and phase-speed) of the weather systems in the runs using regression and lag-regression analyses. In a second step, we studied the linear growth-rate and phase-speed of perturbations applied to basic states from the GCM runs and characteristic of each storm-track. Non-linear lifecycles, using the UGAMP "simple" GCM, which has no parameterisations but the dynamical ones, have also been run to complete our linear study.
We used this method to study the Pacific and Atlantic winter storm-tracks in the UGAMP T42 GCM present day and Last Glacial Maximum (LGM) simulations run in the framework of the Palaeoclimate Modelling Intercomparison Project (PMIP). The LGM climate, constrained by huge ice-sheets over the continents and different sea-surface temperatures, sees significant changes in weather system development. This is most obvious from both approaches over the Atlantic, where LGM perturbations are broader and faster. Thus, studying the single mechanism of baroclinic development on basic states from GCM simulations appears valuable in understanding the storm-track differences and this method will be used to analyse differences between other PMIP runs.

THE DIAGNOSIS OF ANALYSIS AND MODEL ERRORS IN THE NORTHERN HEMISPHERE STORM TRACKS

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The largest NH forecast errors in the medium forecast range occur in the storm track areas of the Pacific and Atlantic. A separation of analysis errors and model errors is normally a very difficult task. Over the oceans where the data density is particularly low analysis errors contribute to a large part to medium range forecast errors. Using adjoint integrations to minimize the day-2 forecast errors the dominant analysis errors can be estimated. Correcting the initial conditions based on the knowledge of these so called key-analysis errors, unstable error growth is substantially reduced and subsequent integrations reach a higher level of consistency than operational forecasts. Integrations from smaller errors in initial conditions therefore form an optimal basis for diagnosing effects from the diabatic processes. In particular beyond the optimization time of two days the integrations from modified initial conditions are used to diagnose the role of diabatic forcing for medium range forecast errors in the storm tracks. The diagnostic technique is based on tracing the redistribution of potential vorticity by diabatic processes.

Issues in determining storm track variability

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The variability of storm track intensity and length is likely to be a major element in the climatic variability of much of the mid-latitudes, especially of those regions located towards the downstream end of the stormtracks, such as western Europe. Attempts to describe or model such variability hinge on what measures of eddy activity are used to define a storm track. The usual approach, using time filtered Eulerian diagnostics can be misleading in several respects. Such Eulerian diagnostics will be compared with results based on identifying and tracking individual cyclone/anticyclone systems and with Hovmoeller plots. It will be shown that these different diagnostics lead to different pictures of storm track variability; an attempt will be made to reconcile these conflicting results.

Some comments on possible mechanisms for low frequency storm track variability will be included. These amount to an attempt to find a local parametrization of high frequency transients.

VARIATIONS OF CYCLONIC ACTIVITY OVER CASPIAN SEA REGION

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Caspian Sea (CS) is characterized by large variations of its level. The CS level has risen on 2.5 m during two last decades. This closed Eurasian water reservoir with the catchment area about 3 million sq. kilometers can serve as a unique indicator of climatic variations. Hydrological cycle in the CS basin is related. in particular, to the North Atlantic and Mediterranean storm tracks. The analysis of observations shows the prominent change of sea-level pressure (SLP) field for the period of the CS level increase relative to the previous period of its decrease. The SLP trends found for some specific regions are related to the changes in atmospheric circulation and cyclonic activity. Characteristics of cyclonic activity in the middle troposphere and near surface over the CS basin are analyzed using different data for last decades. There is a correlation between variations of the cyclonic activity and precipitation over the CS basin. The connection between the regional cyclonic activity and global climate in interannual and interdecadal variability (including El Nino effects and variations of centers of action) is analysed.

NORTH ATLANTIC STORMINESS RE-ANALYSED: NO TREND DURING THE PAST 100 YEAR PERIOD

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A unique new data set consisting of quality controlled mean sea level pressure observations, 3 - 4 times daily, at more than 20 stations in the Northern European and North Atlantic Region has been compiled in digital form as part of the European WASA project. Most of the stations has an almost unbroken 100 year observational record. The pressure data in the WASA data set have been used to estimate the storminess. Here an analysis of storminess is presented which is based on slow variations in high frequency variability in the pressure data. Technically this is done by calculating the absolute 24 pressure tendencies at each observation time. This way of analysing the data, ensures a homogenous record. Different percentiles (50, 10 and 1) of the tendencies are then constructed for each season and year. The resulting time series of percentiles are remarkable stable, showing no overall trends in storminess. However, there are certain important decadal variations. The variations in the identified local storminess can be related to slow variations in the mean pressure patterns over the North Atlantic. A downscaling model is used to investigate if there are trends in this relationship which may reflect interesting variations in the 3 dimensional structure of the atmosphere, possibly related to external forcing of the atmosphere.

MECHANISMS OF ANTHROPOGENIC CHANGES IN NORTHERN HEMISPHERE WINTER STORMTRACKS

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Anthropogenic changes in the regional distribution of synoptic activity are considered. Investigations focus on the role of baroclinicity and the relevance of upstream stormtrack activity to local stormtrack strength. The latter influence is assessed through the *spatial persistence* of the stormtracks, i.e. the spatial distance up to which stormtrack variations are temporally correlated. Both ECMWF analyses and a control simulation as well as a 3·CO_2-experiment with the Hamburg ECHAM3 climate model are examined.
According to ECMWF analyses, spatial persistence is highest in the lee of continental mountain chains and lowest in the eastern oceans. Particularly in the latter regions, stormtrack activity is correlated with baroclinicity.
In the control run, the mean stormtracks and baroclinic zones are reproduced realistically. Their interannual variability is underestimated especially over the Atlantic. The gross features of the interrelationship between baroclinic instability and stormtrack activity are reasonably well simulated.
In the 3·CO_2-experiment, a pronounced increase in spatial persistence is connected with both an intensification of mean stormtrack strength over the eastern oceans and an increase of interannual stormtrack variability over the western hemisphere. Changes in mean baroclinicity are additionally relevant to stormtrack signals over the Pacific while baroclinicity maintains its strength and role over the Atlantic. Possible causes for the increase in spatial persistence are discussed.

THE SEASONALITY OF THE NORTHERN HEMISPHERE STORM TRACKS

P. J. Valdes and **L. C. Shaffrey** (Department of Meteorology, University of Reading, Reading, U. K.)

Storm tracks can be defined as regions of transient eddy fluxes associated with localised regions of high frequency synoptic eddies. During the Northern Hemisphere Winter and Equinox seasons there are two localise d maxima of transient eddy fluxes, the Atlantic and Pacific storm tracks, but th eir seasonal behaviour is rather different. The Atlantic storm track is strongest in Winter, whereas the Pacific storm track is strongest in Spring and Autumn. It is not clear what mechanisms are responsible for the different behaviour of t he two storm tracks.
The present study aims to investigate the maintenance and seasonality of the Pac ific storm track within a simple GCM (Global Circulation Model). The GCM is constrained by restoring the zonal temperature field to an empiricall y determined restoration state, this restoration maintaining a chosen zonal temp erature field. Simple representations of latent heating, sensible heating, zonally varying surf ace friction and orography are included in the GCM.
The resulting DJF and SON Pacific storm tracks are similar to observations but t he observed seasonality of the Pacific storm track is not correctly reproduced. The possible reasons for the failure of the model to account for the seasonal va riation of the Pacific storm track will be discussed.

PREDICTION OF EXTRATROPICAL CYCLONES IN THE UKMO GLOBAL NWP MODEL

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Accurate prediction of extratropical cyclones and their life-cycles is a crucial aspect of the performance of an NWP model. In this study, the aim is to objectively identify whether there are any *systematic* errors in the tracks and central pressures of individual cyclonic systems in the UKMO global NWP model, and to determine the relationship between these "stormtrack errors" and errors in the mean flow.
An objective cyclone tracking algorithm has been applied to five-day forecasts and corresponding analyses over the Atlantic region for the 90 days from 01/12/94 to 28/02/95 at 12-hourly intervals; forecast tracks are associated with their analysed counterparts and errors in position, speed and central pressure are calculated. Examples of individual systems are used to highlight systematic errors and potential deficiencies in the tracking procedure are also discussed. Mean results show that forecast tracks are generally too zonal, deepening lows are too shallow in the forecast, and filling lows are too deep.

AN OBJECTIVE CLIMATOLOGY OF NORTHERN HEMISPHERE CYCLONES AND ANTICYCLONES

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Previous diagnostic studies of the climatology of baroclinic wave activity were based on two different approaches, and served respectively to identify the so-called "synoptic" and "dynamic" storm-tracks. The "synoptic" storm-track equates to the statistical distribution of the paths of cyclone centers as analyzed from sea-level pressure charts, whereas the "dynamic" storm-track relates to band-passed filtered variances of the geopotential height field. The relationship between the two fields is not straightforward; and indeed the "synoptic" storm-track is usually not represented as a mathematical field. This makes quantitative investigation difficult.
Here an alternative technique is introduced for the objective diagnosis of "synoptic" storm-tracks. It identifies closed isolines in the sea-level pressure field, and generates a field which is (within the cyclone) equal to the pressure difference relative to the value of the enclosing isoline. Using NMC analysis data from 1962-1992 monthly mean fields are derived for cyclones and anticyclones on the northern hemisphere. This permits a quantitative analysis of the inter- and intra-annual variability and of possible changes in the frequency, location and intensity of synoptic disturbances during this 30-year time period. Consideration is also given to the possibility of comparing the two types of storm-tracks, using EOF and SVD techniques.

THE VARIABILITY OF CYCLONE STRUCTURES: RESULTS FROM IDEALIZED NUMERICAL SIMULATIONS WITH INCREASING COMPLEXITY

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Idealized model simulations of baroclinic wave development indicate that a range of dynamical and physical factors can significantly influence the structure of the resulting cyclones and fronts. Important dynamical factors are the earth's sphericity, the choice of the initial perturbation, and the shape of the jet-like basic state. The latter can be altered for instance through the addition of a uniform barotropic shear component, and this has been shown to exert a profound influence upon the nonlinear development of normal-mode perturbations.
In this study the effect of barotropic shear is further analyzed for the initial-value problem of upper-level induced cyclogenesis, using a sequence of f-plane experiments of increasing complexity. For an atmosphere of uniform PV with a rigid-lid tropopause both the semi-geostrophic and the primitive-equation frameworks yield similar results and confirm the forementioned influence of lateral shear. The inclusion of a more realistic tropopause leaves the main structural features at the surface unchanged, and permits the analysis of the relationship between upper-level potential vorticity structures and the surface development. Consideration is also given to the storm-track signal related to the two classes of idealized cyclone development, and to the possibility of includin g moist processes to the simulations.

OA21/G11 Measuring and modelling atmosphere-ocean-land interactions

Convener: Gegout, P.
Co-Conveners: Dickman, S.R.; Laval, K.

INTERACTIONS BETWEEN ATMOSPHERIC PRESSURE FIELDS, THE OCEANS, AND EARTH'S ROTATION

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The excitation of Earth's rotation by atmospheric pressure fluctuations, on time scales from days to years, is modified by the oceanic response to the pressure load. That response, including changes in mean sea level and associated currents, cannot be accurately described unless the frequency dependence and spatial structure of the loading are accounted for.
I have calculated frequency-dependent Green's functions which character-ize the rotational effects of the oceanic response to pressure loads associated with individual spherical harmonics. Computations were based on solutions to my dynamic spherical harmonic ocean tide model, with rotational effects determined using a "broad-band" approach. A convolution-type combination of the Green's functions with actual atmospheric pressure data then yields the effects of the "dynamic barometer" oceanic response on rotation. Results for the past decade have been obtained using harmonically decomposed NMC and EC pressure fields. Estimates of the combined atmospheric and (dynamic barometer) oceanic angular momentum time series for 1980 - 1990 will be presented and evaluated.

GEODETIC SITES DISPLACEMENTS INDUCED BY OCEANIC AND ATMOSPHERIC LOADINGS

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Global atmospheric loading induces various interactions between atmosphere and oceans, between atmosphere and solid earth and between solid earth and oceans. We consider the static response of non-global oceans overlying an elastic Earth which is induced by the atmospheric loading located over the continents. This model take into account the significant oceanic response associated with the continental atmospheric loading, relative to ocean - solid earth interaction. Temporal variations of geodetic (SLR, VLBI, ...) sites positions driven by global atmospheric loading and non-global oceanic loading are derived using a global atmospheric pressure data set provided by the European Center for Medium range Weather Forecasts.

THE REPONSE OF NON-GLOBAL DYNAMIC OCEANS TO GLOBAL ATMOSPHERIC FORCING

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To investigate the geodynamical consequences of Atmosphere-Oceans-solid Earth interactions, we present a basic dynamical model of the oceans which include the oceanic response to global atmospheric forcing. The processes of interaction between solid earth and non-global oceans induced by continental atmospheric loading are modelled. Hydrodynamic equations are solved using spectral methods and generalized spherical harmonics. Spectral solutions of the hydrodynamic equations yield for each spatial scale (i.e. for each spherical harmonic's degree and order) the frequency-dependent response of the oceans. For periods greater than ten days, the oceanic response aims to the static equilibrium of a non-global ocean overlying an elastic Earth. We discuss the influence of Earth's deformations on large scales oceanic masses redistributions. We also underline the fact that the daily variability of atmospheric and oceanic masses distributions have major consequences on Earth's rotation.

ATMOSPHERIC LOADING OBSERVED BY VLBI

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Air pressure lows and highs (cyclones and anticyclones) can be regarded as time-dependent loading on the Earth's surface. According to their geometry they generate large-scale deformation fields with some hundred up to some thousand kilometres wavelength. The periods of the loading function are between a few days and some weeks. There is also a diurnal pressure variation corresponding to the solar S_1 tide and an annual period of the global air pressure distribution. Such air pressure anomalies can cause vertical displacements in the centimeter range and horizontal displacements in the millimeter range. The influence of atmospheric loading corrections on the results and the accuracy of VLBI experiments (Very Long Baseline Interferometry) has been investigated. For the site dependent pressure responses a model of Manabe et al. (1991) was used which gives loading coefficients for the most important geodetic VLBI s tations. The amplitudes of local and mean annual air pressure variations can easily be obtained from VLBI station logs and weather charts for the duration of the VLBI experiments. Loading coefficients have also been determined by a VLBI global solution. The correlation coefficients between these coefficients determined empirically and those given by the theoretical model are higher than 0.6. Thus, the VLBI results in general confirm the theoretical model but show signifi cant anomalies for some stations, e.g. for Onsala (Sweden). The validity of the inverted barometer hypothesis was tested by VLBI, too.

APPLICATION OF THE HD MODEL IN THE ACSYS REGION:

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The representation of hydrological land surface processes is still not being treated adequately in atmospheric global circulation models (GCMs). In particular the lateral waterflows from the continents into the ocean have so far been described in an insufficient way. A model was developed which describes the translation and retention of the lateral discharge on the global scale as a function of the spatially distributed land surface characteristics which are globally available. Here, global scale refers to the resolution of 0.5° and lower, corresponding to a typical average GCM gridbox area of about 2500 km^2.

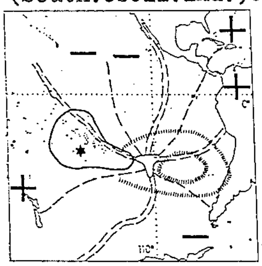
The **Hydrological Discharge model** or **HD model** separates between several flow processes such as overland flow, baseflow and riverflow. As both the retention and translation of a flow process need to be simulated, a two-parameter model is required. In the HD model this is applied to overland flow and riverflow. For baseflow a one-parameter model is sufficient. A first parameterization approach using gridbox characteristics was developed.

The HD model is applied to the ACSYS region using input from several atmospheric GCMs (ECHAM4-T42, ECMWF-Reanalyses, NCEP Reanalyses). The simulated inflows into the Arctic Ocean and its subcatchments are compared to observed inflows which were provided by GRDC. Based on this comparison the quality of the input from the different atmospheric GCMs is judged.

LITHOSPHERE-ATMOSPHERE INTERACTION AND EL-NIÑO

G.G.Kochemasov, IGEM, Russian Academy of Sciences

Wave sectoral structure of cont.hemisphere of 4 alternating risen/+/& fallen/-/sectors(having 8 subsectors)is centred at the Pamirs and has its antipod in ocean.hemisphere:centre in Easter Is. rise/Kochemasov,1995/.Highly risen &"anomalous" Tibet is antisymmetric to South Pacific "Superswell"(*)also anomalous in bathymetry & petrology.Both sectoral structures have mirror reflection in the CMB.High pressure atmospheric cell (inner cont.1020mbar)producing much of the SOI (South.Oscil.Ind.)change signalling beginning of El-Niño,is centred over Chilean subsector.Anomalous spots in lithosphere(Superswell) & atmosphere are opposite in the sector structure.There is tendency to equalize angular momenta of 2 anomalous deeply rooted subsectors separated by Easter Is.& EPR.Ang.momen. exchange is a tool creating ENSO.



EFFECT OF THE TIBETAN PLATEAU UPLIFT ON MONSOON SIMULATED BY THE LMD AGCM

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It has been recently proposed that a large change in the monsoon regime occured about 8 My ago at the end of Miocene and that this change was triggered by a geologically rapid uplift of the Tibetan plateau. The climate simulations performed with the LMD Atmospheric Circulation Model (AGCM) have shown that this model was able to reproduce rather realistically the monsoon variability on seasonal and interannual scales. We have thus used this model to simulate the climate changes associated with variations of the height of the Tibetan plateau through geologic times. The results of the simulations show that the monsoonal atmospheric circulation varies with increasing height of the Tibetan plateau. However, this variation shows regional contrasts over South-East Asia and India that we will discuss. The southwestern winds over Arabian sea are stronger with surface uplift over the Tibetan plateau, but, simultaneously, they are weaker over southern India and the Bay of Bengal. The precipitation changes vary also regionally showing a displacement of the maximum convergence zone in latitude. The results of these simulations are compared with the geologic indicators of climate change in the Indian ocean and within the Himalaya foothills at the end of Miocene about 8 My ago.

Tidal Deformations of the Continental and Oceanic Lithospheric Blocks and Their Differential Westward Movement

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Tidal deformation in the solid earth is a sort of a "high frequency" vibration, acting in a fractured, inhomogeneous substance over a long period of geologic time. These deformations are distributed in the earth unevenly: higher magnitudes of the vertical (radial) deformations are observed in the continental area, and lower radial deformations (due to the dampening effect of the water layer) are observed in the oceanic part of the earth. Besides, it is reasonable to suggest that the tidal deformations are not equally distrubuted along the earth's radius, but rather concenrtrated in one of the layers (probably asthenosphere). To describe adequately these deformations we used a model of a loose medium. The plane problem of "tidal" deformation in a circled area, containing the inner nondeformed core was considered. Two differential equations of the second order, describing lateral motion of a particles, caused by vertical tidal deformations are arrived at. It is shown that the rate of the westward drift of the lithosphere depends on the amplitude of the vertical deformations of the latter. Precisely, this rate is proportional to the amplitude of the vertical deformations squared. The amplitudes of the solid earth tidal deformations in the oceanic areas are lower in comparison with those in the continental areas due to the dampening effect of the water layer. As a consequence, there occurs a more rapid westward drifting of the continental lithosphere than that of the oceanic one.

EARTH ROTATION AND POSTGLACIAL RELATIVE SEA LEVEL HISTORY

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Although it has become commonplace to investigate the impact of the late Pleistocene glaciation-deglaciation cycle upon Earth rotation, there has been less attention payed to the issue of the feedback of such variations in rotational state upon postglacial sea level. Several recent analyses have suggested that this feedback warrants consideration. In Peltier (1994; Science, 265, 195-201) a series of detailed comparisons of coral based and U/Th dated records of postglacial rsl history were discussed, principally those from the Island of Barbados in the Caribbean Sea and from the Huon Penninsula of Papua New Guinea, which suggested that these records were well fit by a global viscoelastic theory of postglacial sea level change but only if the usual corrections for tectonic uplift at these sites were not applied. The theory then predicted the observed 13 m offset between these records that obtains just subsequent to the Younger-Dryas epoch. The implications of this result have recently been debated by L. Edwards and W.R. Peltier (1995; Science, 267, 536-538). Here I will describe a series of investigations performed to determine whether or not the feedback of deglaciation induced variations of Earth rotation upon sea level history is capable of modifying the predicted histories at these sites so as to allow the usual corrections for tectonic uplift to be applied. The analyses are based upon the ICE-4G deglaciation history of Peltier (1994) and mantle viscosity profiles inferred on the basis of formal inverse theory by Peltier (1996; Science, 273, 1359-1364).

THE ANNUAL POLAR MOTION EXCITATION.

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In this paper we study the atmospheric, oceanic and terrestrial hydrological cycle excitation of the annual polar motion. We will particularly devote our presentation to the oceanic excitation as obtained from the analysis of Topex/Poseidon sea level data. We will discuss the steric correction applied (using the Levitus climatology and sea surface temperature) and the different hypothesis for obtaining the oceanic currents from surface measurements. We will also show our results concerning the atmospheric excitation : geographical variation in pressure and their effect in polar motion, and the analysis of different sets of winds. The hydrological components are derived from a run of the UGAMP model with climatological fluxes. Both the soil moisture and snow depth shows little effect when compared with oceanic or surface pressure excitation. After adding the all terms (hydrological, oceanic and atmospheric) the results coincide with the annual polar motion excitation. But the until today negligible reservoirs (hydrological and winds) could be more important than thought, and play a great role on the annual polar motion excitation. This paper also shows the validity of the inverted barometer correction at the annual period.

FRICTION AND MOUNTAIN TORQUE MECHANISMS OF EARTH-ATMOSPHERE MOMENTUM EXCHANGE

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H. Iskenderian

The atmosphere exchanges momentum across its lower boundary by means of both tangential forces of winds against underlying ocean or land and normal pressure gradient forces against mountainous topography. When viewed in the context of the rotating planet, these two actions lead to so-called friction torques and mountain torques that act to change the angular momentum of the atmosphere and the rotation rate of the planet below. Over the ocean, friction torque, which tends to dominate on monthly and longer scales, has been estimated by modeling approaches that are based on surface wind values and the characteristics of the boundary layer. Measurements from scatterometry have yielded new information on the near-surface wind vector, and use of torques based on this approach often improve calculations of the angular momentum balance. On the other hand, mountain torques are particularly strong at the highest frequencies, when they are related to the movement of synoptic-scale weather systems across mountainous features, notably in the winter hemisphere. On such periods of about ten days and under, the Rockies, Andes, and Himalayas have a particularly strong impact on angular momentum exchange between atmosphere and solid Earth.

TWO LAND SURFACE SCHEMES IMPLEMENTED IN THE SAME GCM

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J. Polcher (Laboratoire de Météorologie Dynamique du CNRS, 24 rue Lhomond, 75231 Paris, France)

Land surface processes have a significant impact on near surface climate phenomena. They determine, among others, near-surface sensible and latent heat fluxes and the radiation budget, and thus strongly influence atmosphere and land characteristics such as temperature, humidity or cloud formation. The two land surface schemes ECHAM and SECHIBA which were implemented in the same atmospheric general circulation model (GCM) ECHAM4 are compared. This allows to investigate the role of atmospheric feedback effects which may yield a different evolution of the surface and subsequently the dynamics fields. Global experiments which were performed with the two schemes using the same initialization and climatological sea surface temperatures indicate that the land surface parameterizations have a significantly different impact on the atmosphere. Such differences in the results may be related to certain model characteristics. Global scale results for the atmospheric response to the different land surface schemes are presented. We will analyse the impact on the atmospheric circulation and water cycle and the land surface energy and moisture fluxes.

MULTIPLE EQUILIBRIA AND EIGENMODES OF A SINGLE-GYRE BAROTROPIC WIND-DRIVEN OCEAN CIRCULATION

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G.R. Ierley (Scripps Institution of Oceanography, La Jolla, CA 92093-0225, USA)

A barotropic model of the wind-driven circulation in the subtropical region of the ocean is studied using Chebyshev spectral method. Formation of the recirculation gyre following the separation of the western boundary current from the coast is emphasized. For a geophysically relevant values of viscosity and nonlinearity multiple steady solutions of a boundary-layer, recirculation gyre and basin-filling-gyre types are found. A linear stability analysis reveals several classes of modes: basin modes of Rossby waves, modes associated with the recirculation gyre (resulting in the multiplicity of steady solutions), western boundary wall-trapped modes and a "resonant" mode. Their role in determining the mean ocean circulation and connection to the temporal variability is analyzed.

Non-stationary model of oceanic and atmospheric boundary layers interaction

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Odessa Hydrometeorological institute

The turbulent processes in atmospheric and oceanic boundary layers considered as one system and simulated with the hydrodynamics equations and turbulence closure on the turbulence kinetic energy and dissipation equations. Wave layer processes are taken into account on the description of the wind wave collapsing, which was related with the atmospheric friction velocity. Profiles of meteorological and hydrophysical values, turbulence characteristics and interaction parameters, including the surface currents and temperature of the ocean and turbulent fluxes are determined in common. These functions are calculated to the given conditions on the external boundaries of the interactive layers.

QG, BAROTROPIC, WIND-DRIVEN GYRE MODEL: MODERATE REYNOLDS NUMBER VISCOSITY DEPENDENCE

D. N. Straub and R. B. Scott (McGill University, Montreal, Canada, H3A 2K6)

In the classical view of wind-driven, mid-latitude ocean gyres, energy is input to the geostrophic flow by the winds and is dissipated primarily in western boundary currents and their seaward extensions. This dissipation is linked to poorly known and highly parameterized closure schemes (e.g., eddy viscosities) which are meant to account for the net effect of subgrid scale processes. Both the inverse energy cascade of geostrophic turbulence and the lack of known mechanisms that transfer energy between (quasigeostrophically) balanced and unbalanced flow bring into doubt this view of the energetics. This raises the question of whether the wind power input to the QG flow may shut off as the eddy viscosity becomes small. This question is addressed in the context of steady solutions to the barotropic QG equations, forced by an idealised double gyre wind- stress pattern. This system has multiple equilibria, and the results were found to be sensitive to the dynamic boundary condition imposed and to the symmetry of the solution. In all cases, the the geostrophic velocity and wind fields do decorrelate as the Munk number is decreased. One solution type was found to decorrelate fast enough for the power input to the gyres to decrease with Munk number, even with the lowest Munk numbers investigated. This resulted in solutions that, for some regions of parameter space, had kinetic energy only weakly dependent on the value of the eddy viscosity.

Award applied for: Keith Runcorn travel award

SEASONAL VARIATIONS OF BASELENGTHS FROM VLBI DATA ANALYSIS

O.A. Titov (Institute of Applied Astronomy, Zhdanovskaya str., 8, 197110, Sanct-Petersburg, Russia)

Annual and semiannual variations in baselengths were detected from special investigation of large amount of VLBI data results. Amplitude of both types of them increases with baselength. It means that variations of VLBI station vertical components has the most income into the phenomena. There are a few possible explanations of the effect. For example, strong correlation with AAM functions is observed. It can be interpretated as a influence of global atmospheric pressure oscillations on the Earth crust. Taking into account of the effect will help to increase an accurasy of VLBI data global adjustment in future.

01 Atmospheric and oceanic processes in climate studies

Convener: Le Treut, H.
Co-Convener: Röckner, E.

INTERANNUAL VARIABILITY OF THE MONTHLY MEAN SEA SURFACE TEMPERATURE IN THE NORTH ATLANTIC

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O.A.Goushchin, Kaliningrad State Unniversity

Monthly means on the area 40-60°N, 30-50°W were calculated for the sea surface temperature (SST) data, received by radio from Bracknell, England. The succession 1968-1996 use to have Aug maxima and Feb-Mar minima. There were Apr returns of cold in 1968,69;1981,82,84; 1991 and the strongest one in 1995, from 9,8° (Mar) to 9,2° (Apr). Years above are close to sunspot cycles 20,21,22 extrema. Biennial rhythm started in 1972, the odd years means of SST Aug maxima are warmer than even ones noticeably, 15,4+0,4° and 14,7+0,5° respectivelly, have ceased after great El Niño and similar event in the Tropical Atlantic Ocean (1983-1984). It did not resume hitherto.

NOISE ENHANCE OF PERIODIC FORCINGS IN OCEAN CONVEYOR

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P. Colet (IMEDEA (CSIC-UIB) E-07071 Palma, Spain)
J. Tintore (University of Baleric Islands and IMEDEA, E-07071 Palma, Spain)

Climate records obtained from ice cores reveal that the climate system is capable of abrupt oscillations and transitions from one climatic state to another. These changes can take place on a great variety of time scales. In particular, it has been suggested that oscillations or transitions in the millennial time scale, Dansgaard-Oeschger events, were probably caused by changes in the strength of the ocean's conveyor-belt system, a global-scale overturning characterized by sinking of salty waters in the Atlantic, upwelling in the Pacific ocean, and the return of warm salty water to the northern Atlantic around Africa and South America. It seems then, that some relevant aspects of the climate changes are strongly related with the working states of the conveyor. We present a study where we address the posibility of transitions between the different states of the ocean conveyor induced by stochastic resonance. We have considered the Stommel two box model as an idealized ocean model with a weak periodic density forcing, unable to induce transitions by itself. We have found that in presence of a background noise the forcing can be amplified inducing quasiperiodic transitions between the two equilibrium states with a mean period similar to the period of the weak periodic forcing (stochastic resonance). Extrapolation to the real ocean is discussed.

SEASONAL AND INTERANNUAL VARIABILITY OF THE STERIC LEVEL IN THE NORTH ATLANTIC

V.S.Arkhipkin, I.A.Guseinov, S.A.Dobroliubov (Department of Oceanology, Moscow State University, Vorobyevy Gory, Moscow, Russia, 119899)

Steric level seasonal variability in the North Atlantic ocean from the equator to 60=9CN was analyzed. The steric level was calculated for all months using monthly mean temperature and salinity in one-degree squares down to the 1000 m in relation to the station with areal mean characteristics of the World Ocean. All data were taken from NODC CD-ROM dataset. The individual influence of temperature and salinity was evaluated, and the harmonic analysis of the steric level oscillations was conducted. It has been found out that the amplitude of the steric level oscillations is the highest in the area of the Gulf Stream and near African coast (the upwelling area) where it reaches the values of 12-15 cm. For the most part of North Atlantic the seasonal oscillations do not exceed 10 cm. The phase of the steric level annual harmonic shows that the maximum value almost everywhere takes place in August-September. Thermal component is the basic part of the steric level variability. Spatial variability of the thermal component as a whole repeats the spatial pattern of the steric level motion. The effect of the salinity component on the general steric level is less prominent except for the high latitudes. A seasonal variability of the steric level salinity component is in the counter-phase to the thermal component. Interannual steric level variability is also discussed.

SOLAR ACTIVITY VARIATIONS AND LONGTIME VARIATIONS OF SOME CHARACTERISTICS OF ATMOSPHERE'S THERMODYNAMIC ACTIVITY

Nataly.M.Astafyeva, E.A.Sharkov (Spase Research Institute, Profsoyuznaya, 84/32, 117810 Moscow, Russia)

The temporal scaling properties of Southern oscillations wich closely connected with El-Nino events and intensity of tropical cyclogenesis processes on the timescales from days to decades are examined. The temporal behavior of these characteristics of the atmosphere's thermodynamic activity are compared with the longtime serie of sunspot number (sunspot number does provide a quantitative indication of the solar activity level). We use a set of different techniques to analyse these (and connected) data and to examine their properties. Among the techniques we have used the wavelet transform which allow us to calculate the probability distribution of series and investigate the flatness spectrum - a diagnostic for intermittence (INT-ce characterise the turbulent phenomena). We find that INT-ce of SOI is weak up to 2 months with maximum near 25 days and considerable from 5 to 15 years with maximum near 10 years (there is similar maximum for flatness spectrum of sunspot number but the magnitude do not confirm the INT-ce; sunspot numbers are INT-t only up to 2 years with maximum near 28 days). The global cyclogenesis is INT-t up to 2 months and from 8 mnths to 2 years. At the other timescales the analysed processes are more regular. The results allow us to say that processes are closely connected and that evidently cyclogenesis and El-Nino are the ways for the system ocean-atmosphere to throw off the energy excess at the different time-space scales.

LONGWAVE RADIATIVE FORCING IN GLOBAL CLIMATE MODELS

F. Baer (Department of Meteorology, University of Maryland College Park, College Park, MD 20742, USA); C. Wang, J. Mao and R.G.Ellingson (same address)

Heating/cooling of the atmosphere by longwave radiation has a strong impact on the thermal field in global climate prediction, noted from sensitivity studies of longwave radiation column models (LWRM) currently used in global climate prediction models (GCMs). Focusing on the effects of the LWRM, we have integrated the NCAR/CCM2 for extended time periods with identical conditions, changing only the heating rate algorithm. At present we have run the CCM2 with its own LWRM algorithm, and using the results as a reference have compared runs which included the Morcrette (ECMWF) algorithm and the NOAA/NCEP algorithm. The resulting heating rates and cloud patterns from runs with these algorithms differ significantly from the reference over a two month period. To assess climate scale significance, we have run a number of scenarios differing only in slight adjustments of the initial state. Results of ten experiments with the CCM2 using its own algorithm, and a lesser number of such runs with the two other algorithms noted above will be described. In each run we have varied the initial state slightly, then allowed a two month equilibration period before developing statistics from the succeeding three months, which represent a winter season. Intercomparison of the results of these integrations will be shown and will demonstrate both the climate variability to be expected from multiple runs, and the impact of changing the LWRM in a GCM. To assess the impact of the GCM, comparable experiments undertaken with the NOAA/NCEP GCM will be presented.

CALCULATION OF NON SOLAR HEAT FLUX WHEN OPEN WATER AND SEA-ICE ARE SIMULT ANEOUSLY PRESENT

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In the frame of ocean-atmosphere coupling, the calculation of non solar heat flu x is difficult when open water and sea-ice are simultaneously present under the same mesh of atmosphere. Indeed, strong contrasts of surface temperature and phy sical propertie s exist between open water and sea-ice. This problem arises particularly when, a s for the ARPEGE AGCM developped by Meteo France, only one averaged Sea Surface Temperature for each mesh is seen by the AGCM. In that case, several methods can be used to calculate the non solar heat flux : calculation on each type of surface and weighing by the sea-ice extent, thresho lding according to the value of sea-ice extent and calculation on only one singl e surface, flux repartition over sea-ice and open water using the flux sensitivity of non solar heat flux with respect to the SST ... These different methods are compared using 1D calculations and coupled simulatio ns involving an OGCM (the OPAICE model made of the OPA GCM and a thermodynamica l sea-ice model, developped at Lodyc - France) and bulk formulae modelisation of the atmosphere .

Advection of water vapour and the cold polar tropopause bias in Eulerian GCM's

Mike Blackburn, University of Reading, UK

Climate integrations of ECMWF's forecast model using Eulerian and semi-Lagrangian advection schemes demonstrate a similar sensitivity of high latitude tropopause temperature to dynamical formulation as recently found by Chen and Bates. The ubiquitous cold bias around 200hPa in Eulerian models is largely corrected by using 3D interpolating semi-Lagrangian dynamics, though it is replaced in this model by a cold bias of 3-5K throughout the depth of the troposphere. In the spun-up seasonal climate, radiative heating acts to damp the tropopause temperature differences between the two model versions. However, evidence will be presented that clear-sky radiative effects associated with upper tropospheric water vapour during the spin-up phase force the temperature differences, implicating initial errors in Eulerian advection of water vapour as leading to the cold temperature bias. Associated features of the climate integrations are differences in the seasonal evolution of the mid-latitude jets and Southern Hemisphere polar vortex.

TROPICAL VARIABILITY MODES RELATED TO NORTH ATLANTIC OSCILLATION

R. Bojariu (National Institute of Meteorology and Hydrology, 71552 Bucharest, Romania)

The coupled variability modes of sea surface temperature (SST) and surface wind components from tropical Atlantic have been identified using canonical correlation analysis and principal oscillation pattern method. The monthly means of the two variables have been taken from Comprehensive Ocean-Atmospheric Data Set, for the time interval 1965-1987. Positive (negative) SST anomalies in the northern tropical Atlantic are associated with southerly (northerly) meridional wind anomalies in the equatorial area and with westerly (easterly) zonal wind anomalies in the northern tropical Atlantic. The low frequency component of the time series associated with the identified coupled modes is related to the interannual persistence of the North Atlantic Oscillation (NAO). When the NAO index and tropical time series are low-pass filtered retaining only the components with periods greater than 48 months, a lagged relationship is revealed. The NAO index tends to lead tropical variability with about 11 months.

A STUDY OF ENTROPY GENERATION IN THE CLIMATE SYSTEM

Bogdan-Felix Apostol (National Institute of Earth Physics, Magurele-Bucharest, Romania)
Sabina Stefan (Department of Physics, University of Bucharest, Romania)

A study is presented, of the generation of entropy in the climate system, including the atmospheric and oceanic components. By averaging the well-known equation of entropy generation over a sufficiently long time, we analyze the entropy budget in a stable climate system. For determining the entropic field at the surface of the Atlantic Ocean and the Pacific Ocean we have used a set of daily COADS data of temperature, pressure and specific humidity, provided by the Max Planck Institute in Hamburg. The analysis of the data has been carried out for the summer of 1992 and for the 1991-92 winter. By comparing the summer and the winter values one can notice that the entropic field is higher in the summer than in the winter, because in the summer the phase transitions dominate, thus contributing more to the generation of the entropy. These differences are not so large, as could have naively been expected, due to the fact that the ocean has a larger heat capacity and stores energy, which is later released, as sensible and latent heats. On the other hand, the meridional gradient of temperature is diminished by the oceanic circulation, which contributes further to reducing the differences in the entropic fields between the high latitudes zones and the equatorial zones.

STOCHASTIC MODELLING OF WIND AND WAVE CLIMATE

A.V. Boukhanovsky and A.B. Degtyarev (Institute High Performance Computing and Data Bases, 194291 St.Petersburg P/O box 71, Russia)
L.J. Lopatoukhin and V.A. Rozhkov (State Oceanographic Institute St.Petersburg Branch, 199026 St.Petersburg, 23 line, 2A, Russia)

Winds and waves is subsystem of a World climatic system. The hydrodynamic and stochastic simulation of wind and wave climate is a main tool of it investigation. In contrast to hydrodynamic modelling the stochastic simulation has some advantages: the wave probability characteristics are obtained directly (the input to hydrodynamic models is barometric pressure, than wind and only in the last step - waves); the simulation does not require super-computer and for any region may be produced very quickly.

The climatic characteristics of wind and wave include the synoptic, annual and interannual variation. Each of this range has it own time and spatial scales. The system of stochastic models, elaborated by authors, allow to solve the following main problems:

- estimation of synoptic variability of wind and waves during the storm, with calculation of maximal waves in a storm;
- calculation of climatic wave spectra for various regions of World ocean, including the regions where the observations are almost absent;
- estimation of the waves of n-year return period and confidence intervals for these waves.

The results of simulations were compared with the wave measurements in some Russian seas, Atlantic and Pacific, and showed a good agreement.

The Seasonal Distribution of the Surface Wind Speed in Observations and Climate Model Simulations for the Baltic Sea and the German Bight

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B.-R. Beckmann, G. Tetzlaff (Institut für Meteorologie der Universität Leipzig, Stephanstraße 3, D-04103 Leipzig)

The seasonal distribution of surface wind speed once per day at 12 UTC was studied together with observational data and results taken from model simulations of the ECHAM3 (MPI-Hamburg) CTRL in T42 resolution (i.e. $\approx$ 250 km). For a comparison of model simulations and observational data it is necessary to correct the measured values which are influenced by local effects (shelter, roughness and orography). Subsequently these 'clean' data are normalized with respect to the same surface roughness and as a reference level the 10 m height over sea surface is chosen for being compatible with the simulations. The average wind speed and the 1%, 10% and 50% percentiles, the temporary occurence of stormy weather situations and the return period for extreme events in the modelled and measured data are monthly compared. The results show significant differences between all the realized investigations of measured and simulated data in the region of the German Bight. As for the Baltic Sea the differences are remarkable however they show less significance.

SENSITIVITY OF INDIAN OCEAN HEAT TRANSPORT TO THE SIZE OF THE AGULHAS CURRENT

Harry L. Bryden and Lisa M. Beal (Southampton Oceanography Centre, Empress Dock, Southampton SO14 3ZH United Kingdom)

New direct measurements of the Agulhas Current southeast of South Africa suggest that its transport is about 15 Sv less than previously estimated. The smaller transport is due to the presence of a northward flowing Agulhas Undercurrent underneath the southward flowing western boundary current. Combining the new Agulhas Current structure and transport with the transoceanic hydrographic section across 32°S taken in 1987 results in a poleward heat transport of 0.8 PW, compared with the previous estimate by Toole and Warren (1993) of 1.0 PW. The smaller Agulhas Current transport also leads to a smaller vertical-meridional overturning circulation in the Indian Ocean as the northward flow of deep and bottom waters is reduced by about 8 Sv from the 27 Sv estimated by Toole and Warren. The dependence of meridional heat transport on the size of Agulhas Current transport is then explored in anticipation of the year-long time series of Agulhas Current transport to be derived from the recently recovered UK WOCE I1 current meter array.

ICE-ALBEDO EFFECT ON THE GLOBAL CLIMATIC VARIABILITY

Peter C. Chu, Shihua Lu, and Yuchun Chen (Naval Postgraduate School, Department of Oceanography, Monterey, CA 93943, U.S.A.)

The ice-albedo effect on the global climatic variability was investigated by two parallel integrations (5 years) of a coupled atmosphere-ocean model developed at NASA/Goddard Institute for Space Studies with: (1) a realistic surface ice-albedo, and (2) a replacement of the surface ice-albedo by the surface water-albedo ('absence of ice-albedo effect'). Both cases were initiated from the NCEP atmospheric observations for 1 December 1990, and from the NODC December temperature and salinity fields. Comparison between the two runs shows the impact of the ice-albedo effect on the global climatic variability. Without the ice-albedo effect, (1) the sea-ice content greatly decreases, (2) both Asian and Australian monsoon circulations weaken, and (3) the surface temperature increases drastically.

SENSITIVITY OF MARINE STRATOCUMULUS TO DROPLET NUMBER CONCENTRATION : EFFECT OF PRECIPITATION PARAMETERIZATION

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Marine stratocumulus observations show a large variability in cloud droplet number concentration (CDNC) related to variability in aerosol concentration. Changes in CDNC modify the cloud reflectivity, but also affect cloud water content (CWC) , cloud lifetime, and cloudiness through changes in precipitation (e.g. Albrecht, 1989). Here, we focus on the effect of CDNC on CWC for a horizontally homogeneous nocturnal stratocumulus. Simulations are carried out with the 1-D version of the hydrostatic primitive equation model MAR (Modèle Atmosphérique Régional) developed at the UCL. It includes high-order turbulence closure, and a parameterized microphysics including prognostic equations for water vapor, cloud droplets and rain drops concentrations. The model is first validated on a stratocumulus case observed during ASTEX (Duynkerke et al., 1995). The way of representing precipitation formation significantly influences the simulated stratocumulus. In order to point out that effect, we have tested several parameterizations found in the litterature, and examined how they influence the simulated CWC. Afterwards, using these parameterizations, several simulations are performed to estimate the variations of CWC resulting from changes in CDNC.

DEVELOPING A REPRESENTATION OF THE RADIATIVE EFFECTS OF ANVIL CLOUDS

J.M.Cairns (Hadley Centre for Climate Prediction and Research, U.K. Met. Office, London Road, Bracknell, U.K.)
R.Kershaw (Hadley Centre for Climate Prediction and Research, U.K. Met. Office, London Road, Bracknell, U.K.)

A parametrization of the radiative effects of anvil clouds for use in both climate and forecast global circulation models (GCMs) is being developed. The U.K. Met. Office Unified Model (UM) presently has no representation of anvils. The sensitivity of the UM to convective cloud amount (CCA), convective cloud water (CCW) and the vertical distribution of cloud amounts has been explored. The results of these sensitivity experiments will be described, including the impact on the top of atmosphere radiative balance. Different responses are seen in the tropics and mid-latitudes. Experiments with various anvil shapes are continuing and the latest simulations show good agreement of optical depths with ISCCP data.

AN ESTIMATE OF THE OCEAN-ATMOSPHERE FEEDBACK IN THE MIDDLE LATITUDE

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Extratropical sea surface temperature (SST) and surface turbulent heat flux anomalies in the central and eastern part of the North Atlantic are considered for the period 1952-1992 on a 5° × 5° grid. In this region where the mean surface current is small, the SST anomalies are well simulated by a simple one dimensionnal mixed-layer model which is stochastically forced by the day to day changes in the local air-sea fluxes. A statistical signature of the s tochastic model is that the cross-correlation between heat flux and SST anomalies changes sign between negative and positive lags when the heat flux feedback is negative. Usin g properties of the lag covariance between SST and the heat flux anomalies, the turbulent hea t flux feedback is estimated from the observations. It averages to about $20Wm^{-2}K^{-1}$, increasing toward the northwest and the northeast, and decreasing southward. It also varies seasonally, being larger in the fall, and smaller and more uniform in sum mer. There is no indication that it can become positive. A negative turbulent heat flux fee dback is also suggested by the dominant modes of variability, and it is found that the spatial patterns of associated SST and turbulent heat flux anomalies are remarkably simi lar, with only a change of sign between lead and lag situations.

STOCHASTIC MODELLING OF WIND AND WAVE CLIMATE

A.B. Degtyarev and A.V. Boukhanovsky (Institute High Performance Computing and Data Bases, 194291 St.Petersburg P/O box 71, Russia)
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The results of simulations were compared with the wave measurements in some Russian seas, Atlantic and Pacific, and showed a good agreement.

CONNECTIONS BETWEEN NAO AND ENSO SIMULATED WITH TWO AGCMS : LMD (CYCLE5.3) AND ARPEGE CLIMAT (CYCLE 12D)

C. Dichampt-Martineu and S. Parey (EDF/DER, Environment Department, 6 quai Watier, 78401 Chatou Cedex, France ; * PhD thesis student).

The results of two Atmospheric General Circulation Models are compared to study the interactions between different low-frequency oscillations of the atmospheric system during the Northern hemisphere winter (North Atlantic Oscillation and Pacific / North American mode) and their links with the oceanic forcing (especially with ENSO).

Eleven simulations of each of the twenty-two 1970-71 to 1991-92 winters have been simulated with the LMD cycle 5.3 model (96x72x15) and nine simulations of each of the fifteen 1979-80 to 1993-94 winters have been simulated with the ARPEGE-Climat cycle 12d model (T63 - simulations conducted in the framework of the European project PROVOST).

Singular value decomposition analyses are applied to the monthly means of the oceanic forcing (SSTs) and of atmospheric fields to identify these oscillations and their connections.

INFLUENCE OF ENSO PHENOMENON ON THE AIR CIRCULATION AT MEDIUM LATITUDES

Ioana Dima (Department of Physics, University of Bucharest, Romania)
Norel Rambu, Sabina Stefan (Department of Physics, University of Bucharest, Romania)

The purpose of this communication is to emphasize the way the ENSO phenomenon affects the air circulation in altitude, at mid latitudes. The study was carried out by analyzing the outputs of the AMIP simulation of the general circulation, by means of the atmospheric models CNRM (Toulouse, France) and ECHAMP3 (or MPI, Hamburg, Germany), over the period 1979-1988. We tried to establish a statistical correlation between the ENSO phenomenon, characterized through the time series of the Southern Oscillation Index (SOI), and the anomalies of the geopotential field at 500 hPa and 200 hPa, respectively. One can notice in the correlation coefficient a spatially coherent structure, similar to the Pacific North American pattern. During an ENSO phenomenon this structure is easier to be observed. There is an interaction between the ENSO phenomenon and the atmospheric circulation in altitude, and it results in a train of waves at planetary scale, as shown in the field of the correlation coefficient. The structure of this waves train coincides with that obtained by other authors for the geopotential or wind anomalous field.

AN EASY DETERMINATION OF ATMOSPHERIC INTRASEASONAL VARIABILITY BY DIGITAL FILTERING

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In climatic studies, three types of atmospheric variability are considered separately. Apart from an annual cycle, considerable variability is found in both interannual (IA) and intraseasonal (IS) timescales. Variability of the large-scale circulation simulated by an atmospheric general circulation model may be evaluated in several ways, but a separation into timescales may be helpful. Usually data representing each band is obtained by filtering. A symmetric bandpass linear digital filter is presented which shows some outstanding advantages for easily computing IS variability. These features are: 1) versatility in its design (parameters may be conveniently chosen because an analytic expression for the impulse response function is provided), 2) an optimal performance at the transition band, and 3) the reduction of Gibbs oscillations in the pass band.

The filter has been used to check the ability of the ARPEGE GCM to simulate low-frequency IS variability in middle latitudes independently of IA variations. Results have been compared with those drawn from ECMWF reanalyses and a satisfactory spatial distribution is observed in the model. A slight correction of the maxima eastward shift with regard to the whole (IA + IS) low-frequency variability has been evidenced for IS variability, mainly in spring over the Atlantic. Nevertheless, as in the case of the whole low-frequency, IS variability remains underestimated.

The Seasonal Distribution in Aerological Observations and in a Climate Model Simulation for the Region of Germany.

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The seasonal distribution of geopotential, temperature, humidity and wind were considered for the pressure levels 850 hPa, 700 hPa and 500 hPa. Observational data were taken from the aerological stations Schleswig, Emden, Greifswald, Hannover, Lindenberg, Essen and Stuttgart. The observations were investigated in the time period 1966–1995. The data of the climate model simulation which were used are results from ECHAM3 (MPI-Hamburg) CTRL in T42 ($\approx$ 250 km grid-size) resolution. The 30 year time series from this control run (CTRL) with constant 1985 atmospheric CO_2 concentration and with a climatological sea surface temperature (SST) was considered.

Preliminary results of the comparison between observations and climate model simulation are represented in this paper. The 30 year monthly average, the monthly maximum and minimum values as well as the temporary occurence of extreme events in the meteorological parameters are compared. This work also considers the variability of the seasonal distribution on one hand.in observational data and on the other hand in the results from climate model simulation.

SOME ASPECTS OF THE THERMODYNAMIC ICE-OCEAN INTERACTION IN A GLOBAL OGCM.

M.-A. Filiberti (Laboratoire d'Océanographie DYnamique et de Climatologie)
J.-L. Dufresne (Laboratoire de Météorologie Dynamique), M.-N. Houssais, M. Imbard and G.Madec (Laboratoire d'Océanographie DYnamique et de Climatologie).

The sea ice is a fundamental constituent of the climatic system at high latitudes, in particular through modification of the air-sea fluxes and strong interaction with the underlying ocean.

A thermodynamic sea ice model has been developed and coupled to the global version of the LODYC OGCM in the context of the French climate community activities. The first experiments with this coupled ice-ocean model forced by surface output fields from an AGCM will be analysed for both the northern and southern hemispheres.

Special attention will be paid to the annual cycle of the thermodynamic ice-ocean interaction. The relative contributions of the lateral heat and salt transports and of the convection processes in controlling the ice distribution and the exchange with the atmosphere will be investigated. The role of the salt/fresh water budget in relation to ice growth/melting will also be discussed.

The impact of the fully interactive ice cover will be estimated by comparison with a sensitivity experiment in which the sea ice model is replaced by a simplistic diagnostic sea ice formulation.

REGIONAL AND NON-REGIONAL EFFECTS OF TROPICAL DEFORESTATION

N. Gedney and P. J. Valdes (Meteorology Dept, Reading University, Reading RG6 6BB, U.K.)

The potential impact of tropical deforestation has been a major concern for a number of years. As a result much attention has been given to obtaining observations and performing GCM experiments over the tropical forest regions of Amazonia, South East Asia and Central Africa. The analysis of these experiments has mainly concentrated on changes in the regional surface energy balance.

The ECMWF Integrated Forecasting System (version 12r1) GCM is adapted to include geographically varying soil and vegetation parameters based on a classification system. Using this model, deforestation experiments are implemented by replacing tropical rainforest with degraded pasture. In one experiment all the major rainforests are removed and in another only the Amazonian region is modified. The integrations are of sufficient length to ensure that the major regional and non-regional effects may be fully investigated. The impacts are assessed in terms of the surface energy balance and circulation. Particular emphasis is given to the influence of the Amazonian land-surface.

CHANGES IN DAILY PRECIPITATION EXTREMES AND VARIABILITY (2050-2070), SIMULATED BY THE HADLEY CENTRE COUPLED GCM (HADCM2)

S. E. George (Hadley Centre, Meteorological Office, London Rd., Bracknell, Berks, UK. RG12 2SY)

Among the most significant impacts of climate change are those related to changes in the frequency and magnitude of extreme events. For example, changes in the precipitation pattern could lead to higher instances of floods.
The presentation will discuss the daily precipitation extreme and variability predictions from the Hadley Centre coupled GCM for the current climate, and two perturbed climates. Both perturbed climates simulate the historic rise of green house gas (CO_2), plus an increase of 1% a year from 1990, but differ in that the second of the two has the addition of sulphate aerosol forcing (historical estimates to 1990, and IS92a scenario from 1990).
To verify that the current climate is correctly simulated, comparisons of model data with various observational datasets have been made. The number of observational data points needed to successfully represent a GCM box area average will be addressed, in the context of sub-gridscale variability.
Results from the perturbed models will be discussed for the period 2050-2070, when CO_2 equivalent is double the 1990 level, and three times the control (pre-industrial). Significant areas of change will be highlighted and broken down into their convective and broadscale components.

ON THE INFLUENCE OF VERTICAL MIXING IN A GLOBAL ICE-OCEAN MODEL

H. Goosse, E. Deleersnijder, J.-M. Campin, T. Fichefet (Institut d'Astronomie et de Géophysique G. Lemaître, Université Catholique de Louvain, 2 Chemin du Cyclotron, B-1348 Louvain-la-Neuve, Belgium), M. England (School of Mathematics, The University of New South Wales, Sidney NSW 2052, Australia)

As demonstrated by various studies, vertical mixing is an important phenomenon for the ocean circulation. This is why a comprehensive turbulence closure scheme, namely the Mellor-Yamada level 2.5 model, has been introduced in the Louvain-la-Neuve Coupled Large-scale Ice-Ocean (CLIO) model, the standard version of which using the Pacanowski-Philander's formulation. The impact of this modification on the simulatied World Ocean's circulation is analysed. Close to the surface, the velocity is smaller and the surface temperature extrema are reduced by more than one degree, since the modified CLIO model predicts higher eddy coefficients in the top layers of the ocean. Deep convection and water-mass formation are also significantly affected. In particular, the pathological convection that was taking place around 60° S is noticeably reduced, leading to a better representation of the ice extent.

SPECTRAL GAPS IN ATMOSPHERIC VARIABLES AND REYNOLDS AVERAGING

Andreas Hauschild (Institute of Physics (Meteorology), Humboldt-University Berlin and Meteorological Institute (Theoretical Meteorology), FU Berlin)
Dr.H.-J.Spitzer (Computing Center, Humboldt-University Berlin)

Much work has been done to aquire knowledge about time spectra of the important variables in climate models. This video presents spatial spectra of measured and derived atmospheric variables on the 925, 500 and 50 hPa surfaces on a 3 month period. The basis of the analysis were northern winter 94/95 ECMWF-Data on 2.5x2.5 spherical grid for the times 0.00, 6.00. 12.00 and 18.00 hours. Meridianal and zonal analysis will be presented. In a second step an intercomparison of the Reynolds-, Leonard- and Mixed- terms for two different average lengths will be p resented .
The purpose of the analysis was to compare the applicability of Reynolds average procedure for the transports in different types of hydrodynamic equations (the eulerian, the vorticity and diffusion, and the recently developed nambu-vorticity). There are some surprising results and some verifications of theoretical knowledge, only some of which can be shown. The com plete video is available from the author. Because the time sample used is very s hort, further v erifications of the phenomena found are needed. The author intends to discuss the results in context of predictability in an ora l presentation.

INVESTIGATING SEA ICE VARIABILITY AND ITS RELATION TO ATMOSPHERIC AND OCEANIC FORCINGS.

MN. Houssais and **B. L'Hévéder** (Laboratoire d'Océanographie DYnamique et de Climatologie, Universite P. et M. Curie, CC100, 4 place Jussieu, 75252 PARIS CEDEX 05)

A hierarchy of sea-ice models is used to investigate the sea-ice variability at the seasonal and longer time scales. The ice models complexity varies between a one dimensional thermodynamical one to a fully dynamical-thermodynamical model. The typical scales of the sea-ice response to perturbations in the atmospheric and oceanic forcings will be determined in relation to the important sea-ice processes and atmospheric or oceanic feedbacks.
An application will be presented in order to document and explain some aspects of the variability of the sea-ice cover in the Arctic. Comparison with remote sensing data over the last two decades will help in the interpretation of the results.

DYNAMICAL VERSUS EMPIRICAL DOWNSCALING

E. Kaas, Ole Bossing Christensen and Jens Hesselbjerg Christensen (Danish Meteorological Institute, DK-2100 Copenhagen Ø, Denmark)

An empirical downscaling model has been used to downscale regional-scale tropospheric flow into monthly mean precipitation and near-surface temperature at 20 observation stations in the Nordic region. When verified on independently observed data this model performs very well on temperature while there is less confidence in the downscaled precipitation, particularly in summer. The empirical model has been used to downscale a transient greenhouse gas scenario run with the ECHAM4/OPYC3 coupled GCM. The results have been compared with a control and a scenario time slice downscaling of the same GCM using the HIRHAM4 regional model at 18 km horizontal resolution. Generally, the dynamical downscaling in the control period gives slightly wetter and colder results near the observing stations than the empirical model. The scenario anomalies are generally quite similar using the two methods, particularly for temperature. The empirical precipitation anomalies do, however, show a somewhat different geographical distribution than the dynamically downscaled values. To estimate the magnitude of the errors introduced by using the empirical model to simulate scenario anomalies it has been used to downscale the ECHAM4/OPYC3 direct model output. In this case the empirical model has been trained in the control period and verified in the scenario period. The outcome of this analysis shows that it is crucial to include more predictors - with SSTs as the most obvious candidate - in the empirical model.

POTENTIAL VORTICITY AS AN ATMOSPHERIC CLIMATE VARIABLE

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I.A.Pisnichenko (Center of Weather Forecast and Climate Investigations/ National Institute of Space Research (CPTEC/INPE), Rodovia Presidente Dutra, km 40, Cachoeira Paulista, SP, Brazil; on leave from Russian Academy of Sciences, Obukhov Institute of Atmospheric Physics, Pyzhevsky 3, 109017, Moscow, Russia)

A method of the optimal choice (in the framework of climate theory) of an arbitrary function of potential temperature, entering the general Ertel's potential vorticity (EPV) definition, is proposed. A minimization procedure for informational entropics differences (IED) between actual air mass distributions on EPV values over each Hemisphere and the corresponding statistically equilibrium (Boltzmann) distributions is used. Method efficiency is shown, using monthly mean January and July EPV statistics (1980-89 ECMWF data). Simultaneously, a problem of a reference climate state determination, with the best balanced forcing, is solved. A simplified version of a kinetic equation, that explains both the observed order of IED magnitude (~1% in relative units) and theirs seasonal changes, is proposed.

Vertical profile of solar spectral irradiances from airborne observations in clear sky.

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Aircraft measurements of spectral solar irradiances were obtained in 80-th years above different surfaces in free atmosphere throughout 0.1km from 5 km till 0.1 km. The computer program for processing of these data is made and applied to some of experimental cases. The wavelength dependence of upward and downward fluxes at indicated atmosphere levels are presented.

SENSITIVITY OF A GLOBAL SEA ICE MODEL TO THE TREATMENT OF ICE THERMODYNAMICS AND DYNAMICS

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T. Fichefet (Institut d'Astronomie et de Géophysique G. Lemaître, Université Catholique de Louvain, B-1348 Louvain-la-Neuve, Belgium)

The sensitivity of a global thermodynamic-dynamic sea ice model to degradations of its physics is studied. The model takes into consideration the snow cover on top of ice, the storage of sensible and latent heat in the system, the influence of the subgrid-scale snow-ice thickness distributions on ice thermodynamics, the formation of snow ice, and the existence of leads in the ice cover. Regarding ice dynamics, ice is treated as a viscous-plastic fluid. A single set of parameters is used to simulate both the Arctic and Antarctic ice regimes. The model simulates reasonably well the seasonal cycle of both ice covers. The sensitivity study focuses on: (1) vertical processes (thermal inertia, heat conduction, and snow), (2) lateral processes (leads), and (3) dynamics (ice motion and shear strength). Each experiment consisted in removing a single parameterization from the control run. Neglecting thermal inertia, has a significant effect on the model's response in the Arctic. Snow and of snow ice formation largely affect the modeled ice cover in the Antarctic. The thermodynamic effect of the subgrid-scale thickness distribution, the existence of leads, and the ice motion play a crucial role in the modeled behavior of both ice packs. Ice shear strength has a non-negligeable effect in both hemispheres. We conclude that all these processes should be represented in global climate models.

SHORT-TERM CLIMATE VARIATIONS IN THE NORTHERN HEMISPHERE EXTRATROPICS AND THEIR PREDICTABILITY

W. May (Danish Meteorological Institute, Copenhagen, DK-2100, Denmark)

In our study we investigate the origin of short-term, that are interannual climate variations in the Northern Hemisphere midlatitudes. We also consider the question, to which extent these variations can be predicted. The study is based both on observational data and on data from multi-decadal simulations performed with the ECHAM atmospheric general circulation model. In these simulations observed monthly mean values of the sea surface temperatures (SSTs) and the sea ice extent for the period 1949 through 1990 are given as lower boundary forcing. By means ofthe Canonical Correlation Analysis we are able to identify spatial and/or temporal patterns occurring jointly in two or more fields. In order to find out, to which extent variations of the SSTs in various parts of the globe lead to changes in the large-scale circulation in the Northern Hemisphere extratropics, for instance, these fields include on one hand the SSTs in this particular area and the geopotential height field in the Northern Hemisphere midlatitudes on the other. A prominent example is the impact of the SST-anomalies in the tropical Pacific associated with the El Nio/Southern Oscillation phenomenon on the large-scale circulation in the region of interest. Using the CCA we are also able to construct an empirical model for predicting short-term climate variations based on various combinanations of predictands, that are the fields the prediction is based on. By means of cross-validation we also obtain estimates of the predictive skill of such a model.

PRELIMINARY RESULTS OF A REGIONAL CLIMATE MODEL OVER EUROPE FORCED BY OBSERVATIONS.

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Ch. Tricot (Institut Royal Météorologique de Belgique, Avenue Circulaire, 3, 1180 Bruxelles, Belgium.)

A preliminary simulation of the Regional Climate Model MAR (Modèle Atmosphérique Régional) over Western Europe is presented. The MAR was previously used for several mesoscale process studies, and is now adapted to regional climate modelling : larger mesh sizes (currently 50x50 km) and domains are used, the introduction of large scale conditions from different general circulation models or analyses is implemented, and the improvement of the surface parameters and initialisation for the newly studied region is in progress.
For the present simulation, we use boundary forcing from the new ECMWF analyses and run the model for 2 winter months. Since we seek comparison with observations (and low computing c ost), a moderate domain size is chosen: 2500 x 2500 km + boundaries so that the MAR large-scale flow diverges little from the driving analyses. This work is intended as a first assessment of the model ability to reproduce present climate, and shall define our priorities in improving the model.
In the next step, longer runs will be performed. The model will ultimately be driven by the coupled LMD (Laboratoire de Météorologie Dynamique, Paris) A-GCM / UCL Oceanic GCM.

VALIDATION OF HIGH RESOLUTION 10-YEAR CLIMATE SIMULATIONS OVER THE ALPS

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The present generation of general circulation models have a horizontal mesh size of between 600 and 300 km. In order to quantify the benefits of decreasing the grid size from 300 to 100 km, the CNRM, MPI and UKMO ran their model at this relatively high simulation an AMIP-mode. In a second step, these simulations will be analysed by several groups, each focusing on aspects where they have specific expertise.
The aim of this poster is to present validations of the CNRM run over the French Alps. The Alpine region is critical for climate simulations, because of the orography and of the so-called Mediterranean low-pressure area (which is a major climatic feature of the region). Wind speed, air temperature are validated against the ECMWF analyses. The models outputs are also used to simulate the corresponding snow cover with a downscaling procedure based on analogues. The results are compared to results derived from a low resolution run and the observed snow climatology. The MPI and UKMO runs will be further analysed in the same way.

Simulated changes of the southern hemisphere synoptic variability induced by the removal of antarctic sea-ice

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The impact of the removal of Antarctic sea-ice on the climate simulated by a high resolution version of the LMD general circulation model is analyzed. This study emphasizes the role played by the sea-ice cover on the high frequency variability of the southern hemisphere. We have attempted to explore the connection between the sea-ice, the eddy activity and the mean climate of the extratropical southern latitudes. We analyze the changes in different measures of the synoptic variability, such as the position and strength of the storm tracks, the meridional fluxes of heat and momentum, the eddy kinetic energy and the baroclinicity, in response to a sea-ice-free Antarctic. We also analyze the relation of some major characteristics of the mean circulation to the presence of sea-ice.

MODELLING THE OCEAN RESPONSE TO SURFACE WIND CHANGES

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The ocean response to windstress changes is investigated with an ocean general circulation model coupled to an advective atmospheric mixed layer model. The simulations are based on the Hellerman and Rosenstein wind dataset. The scalar value of windstress has been multiplied by a factor while the direction has been kept unchanged. Several simulations have been carried out with different factors. Wind changes will beside a dynamic effect also have a thermodynamic effect on the ocean circulation through the turbulent surface heat fluxes. Increased (decreased) windspeed will give an increased (decreased) heat loss from the ocean to the atmosphere which influence the thermohaline circulation. Results from the model experiments show differences in the sea surface temperature (SST) distribution. Application of realistic surface heat flux requires calculations of atmospheric thermodynamic response to SST changes. The results from the inclusion of these special effects are presented.

ATMOSPHERIC ENERGY TRANSPORTS AS A CLIMATIC FEEDBACK PROCESSES

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Future climatic modifications in response to radiative perturbations such as the greenhouse effect are subject to important uncertainties, which are the result of the complexity of water vapour, clouds and surface albedo feedbacks. The importance of those local radiative feedbacks may occult the role of the energy transports and their variations, which constitutes an additional feedback mechanism, as well as a factor of uncertainty for the global climatic system. We use the results of two relatively high resolution versions of the LMD AGCM (5.3 cycle), forced by the results of low resolution climate experiments corresponding to present ($1xCO_2$) and $2xCO_2$ climate equilibrium simulations, in order to estimate the possible importance of those processes. The modification of the atmospheric energy transports between the two scenarios correspond to a strong positive feedback at middle and high latitudes for the winter hemisphere. The amplitude of this feedback is similar to that of the radiative perturbations. We show that there exist compensation mechanisms between the variations of the different terms of atmospheric energy transport.

THE CIRCULATION OF A WATER COVERED GENERAL CIRCULATION MODEL AND COMPARISONS WITH SIMPLE ATMOSPHERIC THEORY.

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The results from a series of experiments with an aqua-planet version of the UKMO unified model are compared with the simple theory of axisymmetric models and planetary wave propagation. The model is forced with constant Sea Surface Temperature (SST), the profiles of which are split into two categories (i) zonally symmetric ; (ii) zonally symmetric plus superimposed equatorial anomalies. The resulting time–mean, zonal–mean circulation exhibits either a single ITCZ feature on the equator or twin ITCZ features parallelling the equator, depending on the SST profile used. In the presence of a wave–number one 3K equatorial SST anomaly the equatorial westerlies reach in excess of $45ms^{-1}$. A 3K SST anomaly confined to 60^o of longitude produces equatorial westerlies of the order $6ms^{-1}$. The mechanisms for the production of these equatorial westerlies will be discussed. The planetary wave response to the wave–number one SST anomaly is twice the measured response to the confined anomaly. Convective activity remote from the region of the SST anomaly is suppressed compared to the activity observed using the equivalent zonally symmetric case. These results are suggestive of a strong relation between the shape and nature of a tropical disturbance and the modification of convection elsewhere in the tropical belt.

DECADAL OSCILLATIONS IN A SIMPLE COUPLES MODEL

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To study the dynamics that can lead to decadal oscillations in the North Pacific a simple coupled model was developed. The ocean is based on the linear, reduced-gravity potential-vorticity equation for baroclinic planetary waves. The atmosphere is reduced to a non-local wind feedback to thermocline depth anomalies. The amplitude of the wind stress of spatially fixed structure depends on the thermocline perturbation at one location or in a predefined index region.

Such a simple coupled model produces decadal oscillations for suitable parameter choices. For realistic wind stress pattern the oceanic variability pa tterns are remarkable similar those observed. The period of the oscillations is determined by the speed of the gravest Rossby wave at the coupling latitude. The period of the oscillation is rather insensitive to the coupling strength and amounts to approximately twice the time the Rossby wave needs to travel from the

center of the exciting wind stress curl anomaly to the coupling location.

The stochastic component of the atmospheric forcing was incorporated by a tempor arily white but spatially coherent forcing added to the feedback. With such a forcing , typical oceanic spectra become red with a broad peak at decadal time scales supe rimposed.

IS THE OBSERVED AIR TEMPERATURE INCREASE IN EUROPE DURING OUR CENTURY ANTHROPOGENETIC?

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Antun Marki, B.Sc., Assistant
Dražen Poje, Ph.D., Scientific Adviser

Usual today's scenarios of climatic fluctuations modelling explain the observed temperature increase in Europe by the "green house" effect due to a continuous anthropogenic CO_2 increase in the atmosphere. A testing of this assumption by means of filtered long series of temperature, not alone - but in a comparison to simultaneous series of cloudiness at several locations in Europe, revealed a significant and high positive correlation between those two meteorological elements. Such results suggest that - beside anthropogenic influences - natural climatic variations, related to the general circulation of the atmosphere, are still predominant. The paper gives some possible explanations which take into account the cloudiness interference into a very sensitive balance between the received solar and the lost terrestrial radiations which governs all processes in our planetary atmosphere.

INVESTIGATION OF THE CLEAR-SKY GREENHOUSE EFFECT AND THE WATER VAPOUR FEEDBACK USING GLOBAL SIMULATIONS OF THE RADIATION BUDGET

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Simulations of the Earth's clear-sky longwave radiation budget have been carried out using a new radiation code, developed at the Hadley Centre, with input data taken from the 15-year re-analysis project at the European Centre for Medium-Range Weather Forecasts. The assimilation of observations into the re-analyses includes both conventional and satellite measurements of tropospheric temperature and water vapour. The simulations have been used to investigate the relationship between the vertical distribution of water vapour, atmospheric heating rates and the clear-sky greenhouse effect during the 1982-83 El Niño. The major importance of upper tropospheric water vapour in controlling the amount of longwave radiation leaving the top of the atmosphere is demonstrated. The global nature of the simulations obtained using the re-analyses also allows the response of atmospheric water vapour to an increase in mean SST to be investigated and hence provides important information on the sign of the water vapour feedback. The results have been compared with a recent version of the United Kingdom Meteorolgical Office Unified Forecast/Climate Model forced with observed SSTs to gauge the model's ability to treat correctly the water vapour feedback.

RELATIONS BETWEEN EL NINO / LA NINA EVENTS AND LARGE-SCALE CIRCULATION VARIATIONS

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The relationship between the anomalies of different climatic variables and El Nino/La Nina events have been reported by a number of authors. The main idea of the approaches generally used is to develop a relationship between different ENSO phases and large-scale patterns of atmospheric circulation over the area examined. Then, an analysis of atmospheric circulation patterns (CPs) is used to explain the linkage between large-scale forcing and local climatic response via a conditional probability framework. Given such a relationship the accuracy of estimating local climatic variables using ENSO information is expected to increase. In our examination, the CP types were defined first by using a principal component analysis and the CP type time series were described statistically. Then, the time series of ENSO indices were analyzed and described. Hemispherical large-scale circulation was compared for El Nino and La Nina events. The frequency distributions of time series of CP types under different ENSO phases were compared. Then, new systems of CP types were defined for El Nino and La Nina events separately. These two systems of types were also compared. This procedure was used for midlatitudes in the Northern Hemisphere (Atlantic European and Western U.S. region).

THE CoPIVEP INTERCOMPARISON

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During an informal meeting in june 1996, it has been decided to organized an intercomparison of coupled-GCM about Coupled Processes and Interannual Variability in the Equatorial Pacific (CoPIVEP) in 1997. Until now, the laboratories involved in this project are the Max-Planck-Institut (Germany), the UGAM (United Kingdom), the Meteorological Research Institute (Japan), the University of California Los Angeles (U.S.A.), the CERFACS (France) and LMD (France).

The motivation of this project comes from an explicit formulation of equatorial coupled processes, which could be involved in the interannual variability (Pontaud and Thual, QJRMS, submitted).This formulation could allow a measurement of the growth rate and the propagation of the anomaly depending on the basic state (either the total mean or seasonal monthly mean) process by process.

The main goal of the intercomparison is to verify an eventual link between the nature of the interannual signals, the mean state and the CGCM configuration through coupled processes. Results from a coupled simulation of CERFACS suggest a link between the location of the interannual signal with the mean state and a link between the seasonal variation of the SST zonal gradient with the seasonal phase lock of the warm events onsets. Others results will be presented from a simulation of the Zebiak and Cane model and probably from a simulation of the MPI.

CLIMATIC VARIABILITY OF THE MID- TROPOSPHERIC CHARACTERISTICS IN THE NORTHERN HEMISPHERE IN WINTER

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Climatic variability of the 500 hPa heights over the different parts of the Northern Hemisphere in winter are considered. Areas of the maximum variance of the 500 hPa height were determined. They were chosen as base points for the investigation of the correlation connections in geopotential field in winter. Analysis of the maps of the isocorrelates revealed main features of the global atmosphere processes and determined teleconnections in the middle troposphere both planetary and regional scales. Agreements of the large-scale atmosphere processes in the different parts of the Northern Hemisphere and differences between the atmosphere circulation over continents and oceans have been studied in detail. Constructed maps of the isanomalies exhibit the distribution of the planetary heat sources and sinks in the middle troposphere. Their variability is connected with the ocean-atmosphere interaction and greatly influence the long-term oscillation of the atmosphere processes.Interannual variability of the indexes of the atmosphere circulation was studied. Differences and similarity of the zonal structure of the fluctuations of the mid-troposphere characteristics between the sectors of the Northern Hemisphere have been demonstrated.

THE BLACK AND THE CASPIAN SEA LEVELS - THE INDICATOR OF REGIONAL CLIMATE CHANGE

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As well known the internal basins are the good indicators of the climate change. Their volumes (areas, levels) respond to changes in precipitation and evaporation integrated over the seas and their catchment basins. The catchment basins of the Black and the Caspian seas occupy more than 50% of the European territory. Therefore the largest part of the Atlantic moisture gets to the catchment basins of the seas and forms the river inlet and sea level change. We carried out the quantitative description of the long term sea level change of the Black and Caspian sea and tried to connect them to climate change over the European region. In order to distinguish the climate signal from other factors we've considered simple mathematical model of the sea-level variations. The model realization have been performed on the basis of the tide gauge records and included such procedures as lowpass filtering, EOF analysis, spectra analysis, polynomial approximation. The analysis of the model results allow us to establish the main tendency of the long-term level change of the inland seas- slow falling of the sea level during the current century. The extremes of the sea level change are in good agreement with well known climatic events. To understand the reason of sea level trend and extremes we considered Caspian sea level change for last 3 thousand years reconstructed in accordance with morphometric research of the Caspian coast. We found that the trend and extremes of the Caspian sea level can be presented as part of the long time climate variations with period 110, 200 and 600 years.

A NEW FREE SURFACE FORMULATION FOR CONSERVING SALT CONTENT IN AN OGCM

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On climatic time scales, salt content of the ocean is conserved with a very good accuracy. A salt conservation constraint in an OGCM is more realistic than a constraint of volume conservation although the former condition is more difficult to implement because of the rigid lid assumption. Solutions have already been developed for conserving salt and preserving the rigid lid assumption but only for time scales larger than a decade (Huang, 1993). Here a new formulation is presented that both satisfies the salt content conservation and is valid for shorter periods. It is based on (1) a resolution of the free surface equation and (2) a variation of the first level thickness following the free surface so that the volume of the model varies. Point (1) is achieved by introducing an ad hoc term in the momentum equations that selectively slows down and damps fast long external gravity waves ; for slower waves, its influence tends to zero. This term is computed implicitly so that the model time step can be large. This free surface formulation allows point (2) to be easily implemented. Varying the volume ensures integral constraints such as conservation of energy, salt and heat content.
The method has been implemented in OPA, the OGCM developed at LODYC, and has been tested in a global ocean configuration. The improvements are illustrated by a comparison with a rigid lid formulation.

IMPACT OF GREENHOUSE WARMING ON TROPICAL CYCLONE GENESIS: A DIAGNOSTIC STUDY USING GCM SIMULATIONS

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Possible future changes of tropical cyclones (TC) formation are estimated by computing the Yearly Genesis Parameter (YGP) proposed by Gray (1975) using the results of climate simulations with the atmospheric general circulation model (GCM) of Météo-France. The simulated YGP reproduces the geographical distribution of the current observed frequencies of tropical cyclone formation. In simulations with doubled carbon dioxide concentration the YGP shows a large increase of total cyclogenesis frequency, which is due to the ocean thermal energy factor in the thermal potential. After a critical analysis of the use of a fixed temperature threshold in the diagnosis of tropical cyclones frequency, we propose a modification of the YPG using the convective precipitation computed by the GCM. For the simulation of the present climate, this modification only marginally affects the geographical distribution of TC genesis. For the doubled CO_2 case, the modified YGP diagnoses a more limited increase in TC genesis in the Northern Hemisphere, and a small reduction in the Southern Hemisphere, which seem in better agreement with other recent modelling studies using high resolution climate models.

THE HYDROLOGICAL CYCLE IN REANALYSES AND OBSERVATIONS

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An evaluation of the components of the hydrological cycle from the recently completed ECMWF reanalysis (ERA) is presented. ERA data is compared to the reanalyses from NCEP and NASA as well as analyses and observations from different data sources and several satellite estimates.
Judged from gauge and satellite data, ERA is superior to the NCEP and NASA reanalyses in the extratropics, but no clear decision can be made in the tropics. There are some problem regions in ERA, including the Andes where too much precipitation is reanalyzed and the Alps and Antarctica, which are too dry. Some large year-to-year trends are visible in the ERA data, especially over Africa. The spin-up in the short-range forecasts, as a measure of the internal consistency of model and observations, remains a problem. These problems will be discussed in detail.
None of the reanalyses has a closed hydrological budget, as judged from long-term means of the difference of precipitation and evaporation (P-E) and from observed river discharge. Possible causes are addressed.
The potential benefit for the construction of global precipitation datasets like GPCP is also discussed.

AN ANTARCTIC CIRCUMPOLAR WAVE IN A STOCHASTICALLY FORCED OGCM

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The Hamburg Large Scale Geostrophic (LSG) OGCM has been stochastically forced by anomalous fluxes derived from a ten-year integration of an AGCM using AMIP-forcing. The variability in near-surface temperature and salinity is dominated by a mode in the Southern Ocean having a 7 year time scale. The anomalies are strongest in the Pacific sector and are advected by the ACC. Part of them travel northward along the South American coast, another part enters the South Atlantic and even the South Indian Oceans. The mode is robust in the sense that it occurs in different versions of the LSG model and with different surface boundary conditions. A connection between the decadal variability in our model and the recently discovered Antarctic Circumpolar Wave is postulated.

A COMPARISON BETWEEN FIVE TWO LAYER MODEL SIMULATIONS OF THE 1985-1992 THERMOCLINE DEPTH ANOMALIES IN THE TROPICAL PACIFIC

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A two layer model of the tropical Pacific has been forced with five different surface wind stress fields to simulate the thermocline depth anomalies during the 1985-1992 period. Two of these fields are derived from surface marine reports at the Florida State University (FSU), using a constant and a stability dependent drag coefficient. The others were obtained from three extended AMIP runs made with the ARPEGE T42 model developped at MétéoFrance, the ECHAM3 T42 model developped at the Max Planck Institue Für Meteorologie in Hamburg and the atmospheric model of the Hadley Centre.
The simulations are compared to a new bimonthly analysis of the 20°C isotherm depth based on ship and moored buoy measurements. To get a quantitative measure of the differences between modelled and observed fields, we use the multivariate model testing procedure of Frankignoul. It is found that the simulations based on the FSU product and the Hadley Centre wind stresses are significantly more realistic than those based on ARPEGE or ECHAM3 wind stresses. However, considering the multiple simulations as representative of the forcing uncertainties shows that the latter are unable to explain some of the model-reality discrepancies, in particular in the eastern tropical Pacific.

DESCRIPTION OF A COUPLED EXPERIMENT WITH AN ATMOSPHERIC GCM AND A TWO LAYER TROPICAL PACIFIC MODEL

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We describe here a 28 year experiment with a coupled ocean-atmosphere model. Its atmospheric component is a GCM and its oceanic component is a two active layer model of the tropical Pacific. The technique used for the coupling relies on the concept of a delocalized physics i.e. the spatial resolution of the physics of the atmospheric component is the same as the spatial resolution of the oceanic model. Thus, some of the difficulties linked to the interface conditions are avoided. The experiment has been made with a climatological sea surface temperature outside the area where the coupling works. No flux corrections are applied.
The sea surface temperature presents a warm bias about 1°C but the model does not drift. The seasonal cycle is fairly well represented comparatively to many other models, with a cold period between September and January and a warm period between March and June. There is also a clear interannual variability. The amplitude of the anomalous events reaches 1°C; however, this variability is mainly located in the central east Pacific and remains too weak off the coast of South America.

COMMON CHARACTERISTICS OF THE LONG PERIOD CHANGIABILITY OF OCEAN PROCESSES IN THE REGIONS INFLUENCED BY THE UNIFORM GLOBAL CLIMATE FACTORS

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Joint analysis of the peculiarities of long period fluctuations of regime elements of the Baltic and White seas (temperature, salinity, sea level) was made. The common characteristics of the large-scale changiability of the elements were revealed. The main climate and regional factors which influence the decadal tendency of the sea level were found by spectral and correlation analyses. The multifactor analysis was used for identification of "common" factors which defined the interannual fluctuations of the sea level in the seas of the European sector of the North Hemisphere. The "common" factors picked out as a result of the multifactor analyses were identified by connecting them with global atmospheric and other natural processes.

ON POSSIBLE INFLUENCE OF AEROSOL PART OF SOLAR RADIATION ATTENUATION ON TEMPERATURE CHANGES IN THE ATMOSPHERE

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The present work is devoted to the theory of attenuation of solar radiation at its propagation in the Earth's atmosphere due to atmospheric aerosols. The original model of spatial and temporal distribution of aerosol particles in the turbulent atmosphere lays it the basis of the theory. The distribution model allows to obtain data about distribution of concentration of aerosol particles as in local as in global scale. Using the data about concentration fields as an initial parameters we solve the equation of radiation transfer in turbulent media using delta - Eddington approach. This allows us to obtain the data about radiation flux in the layered model of the atmosphere we used for our calculations. The main optical properties of certain type of aerosol particles were calculated according to the Mie's theory in assumption of sphericity of particles. Following using the equation of energetic balance for each layer we can find corresponding temperature changes in it.
As one of the practically interesting results the values of solar radiation attenuation at the maximal possible aerosol particles concentration (these data was obtained from distribution model) was calculated and estimation of corresponding temperature changes in the atmosphere was done. The calculations shows, that at certain atmospheric conditions the atmospheric heating due to aerosols absorption of the solar radiation can reach 0.3 - 0.6 degrees per day.

AIR-WATER INTERFACE: IN SITU AND REMOTE SENSING MEASUREMENTS.

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The air-water interface is here studied by means of a methodology which employs the surface roughness analysis. This methodology makes use, for in situ measurements, of a new kind of interferential sensor capable of measuring the bidimensional ripple's spectrum up to the capillary region. For the remote sensing measurements are employed either multi-band coherent impulsive radar scatterometers and air/space born SAR systems (Synthetic Aperture Radar) for high resolution imaging. The studies concern, besides sea roughness and wind stress, the rheological conditions of the water surface influenced by the presence of soluble and insoluble, natural and man-made substances. Here are presented the measurements performed either on sea and in laboratory, by means of a tank, in which the effects of several substances and concentrations were analyzed. It is finally shown the possibility of quantifying the presence of substances and theirs effects on the energy and mass exchanges at the air-sea interface.

Evaluation of optical parameters of strati clouds on base of ground radiation measurements.

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Strati clouds impact strongly on energetic regime of the atmosphere and on climate of the Earth by reason of their big extension and duration. It is important to take into account the interaction between clouds and visible solar radiation in climate and weather simulation. Thus the investigation of optical and radiative properties of strati clouds is very timely now. For solving of this problem the ground radiative measurements were carried out in different regions and by different instruments. The asymptotic formulas of transfer theory were applied to interpretation of the ground radiative observations. The single scattering albedo and the optical thickness of the cloud layer observed were obtained.

CHANGES OF THE OCEAN THERMOHALINE STRUCTURE AT 36°N IN THE ATLANTIC OCEAN

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Temperature and salinity of the upper 2000m data from 42 repeats of the hydrographic section along 36=9CN (from Gibraltar to 60=9CN) covering the time period 1971-1984 are analyzed in sense of seasonal and interannual variability of the thermohaline structure. The seasonal signal induced by the ocean-atmosphere exchange processes is well defined in the upper 200m. There is also evidence of the seasonal cycle in the local areas of the section, characterized by relatively strong horizontal gradients, at levels as deep as 1500m. This variability is associated with the thermocline response to the seasonal changes of the large-scale wind curl. The interannual variability of temperature and salinity is found to be quite different at different parts of the section. The upper layer of the eastern part of the section experienced permanent cooling during the whole time period (10=9CC) accompanied by the decrease of the salt content (0.3 psu). The reverse tendency was spotted at intermediate levels with even greater magnitude (1.6=9CC and 1.4 psu). The density changes dominated by the salinity. In the western parts of the section the time evolution of the thermohaline structure was noted by an increase of temperature and salinity in mid 70s in the whole 2000m layer. The increase has been more pronounced at the intermediate levels (22=9CC and 0.13 psu at 1000m against 10=9CC and 0.08 psu at 250m). In this region the density changes were governed by the temperature variations. In the central parts of section temperature and salinity had a more complicated behaviour and no significant changes were found.

SOME FEATURES OF THE CLIMATE FIELD TRANSFORMATION ON THE UKRAINE FOR LAST 100 YEARS

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The analysis of materials of instrumental meteorological observations accumulated for the last 100 years reveals that the climate of Ukraine has been really changing and these changes seem to be a regional response to overall warming caused by antropogenic enhancement of an atmospheric green-house effect. The complex analysis of empirical data allows definite conclusions that at the territory of Ukraine during the last 100 years the transformation of temperature and precipitation climatic fields had the following features: 1) high level of year variability of monthly land-surface temperature and month amounts of precipitation with a sharply defined seasonal variation. Year variability is formed by independent fluctuations and long-term oscillation of unknown nature; 2) a gradual equalization of climatic temperature and precipitation fields were at the global warming. It is discussed the possible physical mechanisms, forming the anomaly spotted structure of climatic rainfall in the Central Europe under the overall global warming.

THE INFLUENCE OF INTERBASIN EXCHANGE ON THE STABILITY OF THE THERMOHALINE CIRCULATION IN THE ATLANTIC

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One of the main questions concerning the stability of the thermohaline ocean circulation is whether another circulation pattern could be stable under present day forcing. If so, the processes have to be identified which are responsible for maintaining the actual mode of circulation. One of the potential processes is Agulhas leakage, and the resulting interbasin transports of salt and heat, which might precondition the Atlantic Ocean for forming deep water.
We consider this hypothesis using a zonally averaged ocean model, which is forced by mixed boundary conditions. Steady states of this model are followed through parameter space, using a path-following technique. Starting from the purely equatorial symmetric problem, we study the effect of adding lateral fluxes of heat, salt and buoyancy on the structure of the equilibria.
We show that the stability of the northern sinking mode is considerably increased by both lateral fluxes of heat and salt. These results are robust when changing the momentum balance of the model, e.g. by adding rotation and windstress.

The Atmosphere as a colloidal medium: climate implications

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An overview of recent studies on "excess" absorption of solar radiation by clouds has been made. The principle result of the overview is the demonstration of the multicomponent nature of short-wave radiation (SWR) absorption in the atmosphere. It has been persuasively shown that clouds is a significant absorber of SWR and it is very important in this context to take into account 3-D spatial inhomogeneity of cloud cover and cloud pollution due to natural and anthropogenic sources of aerosol pollution. There are, however, other important contributors to SWR absorption. For example, contribution of water vapour absorption is far from being adequately assessed. Much more reliable observations and assimilation techniques (to consider observation data from different sources) are necessary to avoid relevant biases. An unacceptably high level of the underestimation of SWR absorption in the atmosphere by the present-day climate models (the disagreement with observations is an order of magnitude larger than the enhancement of the atmospheric greenhouse effect due to CO_2 concentration increase) makes it necessary to develop further research with the two principal purposes: 1). complex dedicated field experiments to study SWR absorption in real atmosphere; 2). more adequate radiation parameterisation in cloud models.

TO THE CLIMATIC STATE MODELING OF THE ATMOSPHERIC CIRCULATION AND A BOUNDARY CONDITIONS INFLUENCE (QUANTUM HYPOTHESIS).

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There is well-known definition of a climate as a "statistical ensemble of states." It puts in the forefront the probability looking at the climatic processes analysis, whereas the most complex and difficult models of a climate - the atmosphere and ocean general circulation models are properly dynamic ones. In the view of an author these two lines may be combined within quantum approach frame for wave function of a climatic macrosystem. The initial point of so conversion to probability description of the Earth climate is the evidence of conformity of the kinetic equation for distribution function and the wave equation. In so looking the fundamental constant describes the integral representation of interaction potential of two particles. The extended quantum approach and irreversible of the operator of an interaction with environment made feasible a Lapunov function as enthropy of this system. By this means the operator of "boundary conditions" permit to describe a motion to an equilibrium state, which can be conceived of as a sum of eigenstates. For atmosphere "an environment" is the global ocean, land and space. Using decomposition of atmospheric circulation on eigenforms reduces variety of possible motions of atmosphere and allows consideration the natural variations of a climate at a "constant" boundary conditions.

SEASONAL CLIMATOLOGY IN THE MEDITERRANEAN SEA USING SPATIALLY AVERAGED DATA OF ERS1-ATSR

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We present seasonal mean fields of Sea Surface Temperature (SST) in the Mediterranean Sea using Spatially Averaged Sea Surface Temperature (ASST) data derived from ATSR radiometer of ERS-1 satellite. The period considered is April 1994 - March 1996. The ASST data, of 50 km of resolution, were averaged taking into account the standard deviation of each datum. The resulting SST fields are analysed in term of their spatial pattern and seasonal variability. Selected areas of the Mediterranean have been studied by comparing the SST maps with the wind fields provided by ECWF of Reading, with the aim to highlight the influence of seasonal wind system. For example, there is a correspondence between the spatial structures of the Etesian winds and of the SST which shows a strong temperature gradient between a cooler area offshore Turkey and a warmer one in the Southern Egean Sea. The SST maps show some of the characteristic features of the marine circulation, such as the presence of the cyclonic Rhodes gyre in the Levantine basin, and the inflow of the Atlantic water, entering through Gibraltar, affecting the sea surface temperature pattern.

OA23 Climate variability: observations and modelling

02 Seasonal to interannual variability: tropical climate predictions

Convener: Slingo, J.M.
Co-Convener: Laval, K.

ROLE OF INTRASEASONAL VARIABILITY IN THE SEASONAL MEAN AND INTERANNUAL VARIABILITY OF THE ASIAN SUMMER MONSOON

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Intraseasonal variability (ISV) at timescales of 30-50 days (northward moving) and 10-20 days (westward moving) is a dominant feature of the Asian Summer Monsoon, giving rise to the active/break spells in monsoon rainfall. It is expected that the seasonal mean monsoon rainfall may be influenced by the statistics of the ISV. ECMWF Re-analysis (ERA) data for the period 1979-1993 have been used to construct a climatology of the ISV of the monsoon. The statistics of the ISV are examined to understand the influence of ISV on the seasonal mean monsoon and its interannual variability. The results obtained from ERA are validated against the observed daily Indian rainfall series and daily OLR from AVHRR.

SEASONAL AND INTERANNUAL VARIABILITY OF PRECIPITATION AND TROPOSPHERIC HUMIDITY IN THE TROPICS

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In studies that require estimates of the sensitivity of water vapor concentartions or rainfall to changes in global-mean temperature, seasonal or interannual variability is somteimes used as a surrogate for global warming. In order to assess the validity of this approach, the seasonal and interannual variability of precipitation and tropospheric humidity in the tropics is documented using satellite based datasets (MSU, HIRS), as well as NCEP reanalysis fields. The analysis focusses on the robustness of the relationship between regional events (monsoons, ENSO) and the variability of tropical-mean quantities. The reproducibility, both from dataset to dataset, as well as from event to event, of the observed relationships is investigated.
The ENSO related variations in precipitation largely consist of a spatial shift of regions of heavy rainfall. In the case of humidity, moist anomalies in the regions of enhanced convection are accompanied by dry anomalies in the regions of associated subsidence, i.e., for both variables compensating anomalies of opposite sign make it difficult to obtain meaningful global scale averages.

INTRASEASONAL KELVIN WAVES IN THE TROPICAL PACIFIC

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Equatorial Kelvin waves are a prominent component of the intraseasonal variability in the tropical Pacific. While the linear theory of these waves has long been known many aspects of their behaviour, for example their relationship to the ENSO cycle, remain poorly understood. In recent years the development of the TAO array and the availability of accurate altimetry have greatly increased our knowledge of intraseasonal Kelvin waves. The use of this data in conjunction with numerical models offers an unprecedented opportunity for detailed study of these waves.
We are investigating the behaviour of intraseasonal Kelvin waves by comparing TAO and TOPEX/Poseidon observations with numerical simulations using a high resolution ocean GCM forced by surface forcing fields from the ECMWF reanalysis project. We have achieved a good simulation of the Kelvin wave activity in the period 1980-1993. Particular attention has been focused on examining how Kelvin waves influence sea surface temperature, and the way in which Kelvin wave propagation is modified by slow changes in the background state. Both these issues are of central importance for understanding whether intraseaso nal Kelvin waves play a significant role in the ENSO cycle. Results of model comparisons with the observations will be given.

ENSO RECONSTITUTION IN SOUTH PACIFIC BY GEOCHEMICAL TRACERS FROM MOOREA CORE OF *PORITES LUTEA*.

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Variation in the El Niño/Southern Oscillation (ENSO) system generates most of the inter annual variability observed in global climate, and its behaviour is not well understood. In order to reconstruct ENSO variability in the tropical western Pacific, we analysed $\delta^{18}O$ and $\delta^{13}C$ on a period of 100 years (1990-1890), with a bimensual resolution, through a 300 year core from a massive head of *Porites lutea* collected in Moorea lagoon (17°30' South latitude and 149°50' West longitude, French Polynesia). The resulting series are compared with some environmental climatic parameters (temperature, radiation, precipitation) measured *in situ* at Tahiti station. At Moorea, the occurrence of ENSO event is characterised by a weak increase in sea surface temperature and a small cloudiness implying more intense solar radiation, which could affect strongly both oxygen and carbon isotopic compositions. In this coral core, from oxygen isotopic profile we identify the strongest ENSO phenomenons, reported by Quinn (1987) and Wright (1988), in 65% of events. If only 65% ENSO events are identified on annual oxygen isotopic signal, 85% are observed in annual $\delta^{13}C$ amplitude record. More, we can classify these ENSO events as strong or weak phenomenon. Such an isotopic study performed in French Polynesia would permit us to make an inventory of ENSO events, which have occurred in the Central South Pacific over the last 300 years and to compare this inventory with other data obtained into Pacific.

ON THE NATURE OF THE ANNUAL CYCLE AND ITS ANOMALIES

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Recruiting concepts of chaos theory, a unifying conception is inferred, from a first in-depth analysis of the systems-dynamic core hidden in the climate of a General Circulation Model, of the planetary-scale summer monsoon (PSM), the annual cycle (AC), the Tropospheric Biennial Oscillation (TBO), and the Southern Oscillation (SO). Phase space projections in integrals of motion suggest a-low dimensional dynamics relating today's anomalies to topological essentials of a stage along routes to chaos the atmosphere-land system appears to follow. The present-day AC is viewed as a forced limit cycle which loses its stability during boreal summer under the influence of attractor sets constituting a torus segment in phase space the minor orbit of which being occupied by a generic, oscillatory PSM. Aimed at understanding the range of control this manifold exerts, a detailed structural analysis is given. At the expense of the more complex view on the AC, simplified notions emerge on both genesis and interaction of its two coexisting subharmonics, TBO and SO.

GCM MODELLING OF THE ASIAN SUMMER MONSOON AT DIFFERENT HORIZONTAL RESOLUTIONS FOR 1986-1989

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As part of the EEC funded SHIVA project (Internet address of the project is http://www.met.rdg.ac.uk/ugamp/shiva/shiva.html), we have performed a set of different horizontal resolution simulations using version 2 of ARPEGE/CLIMAT, the atmospheric general circulation model at Météo-France. A study is being made of the impact of horizontal resolution on the representation of the Asian summer monsoon. Spectral T63, T42, T31 and T21 horizontal resolutions have been used and correspond to grid spacing of 1.9°, 2.8°, 3.8° and 5.8°, respectively. The monthly sea surface temperatures and sea-ice extent were prescribed from COLA-CAC analyses. Initial conditions were constructed using the ECMWF analyses from the re-analyses project. We covered premonsoon and monsoon period by running the simulations from the first day of March until the end of September for 1986, 1987, 1988 and 1989. Results will be presented from these simulations and some remarks will be made concerning the minimum horizontal resolution necessary to give a reasonable representation of the Asian summer monsoon in its seasonal variability.

THE TRIDENT MODEL: AN INTERMEDIATE COUPLED MODEL FOR ENSO STUDY. ANALYSIS OF ENSO VARIABILITY OVER THE 1980-1996 PERIOD

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An intermediate ocean-atmosphere coupled model based on a physics similar to the Cane and Zebiak model was developed. This model, called TRIDENT, is composed of a baroclinic ocean model, an Ekman surface current model, an SST equation and a statistical atmosphere (Syu et al., 1995). Each component of the model was first thoroughly validated to various data sets collected during the last decades. New parameterizations were developed and were shown to improve the model simulations in both forced and coupled contexts. Most of all, the model is simulating in a coupled mode similar amplitudes, patterns and propagations as the ones observed on interannual time scales. The coupled model initialized first without any data insertion is found to have a better skill in forecasting observed ENSO variability than the Cane and Zebiak model. The insertion of sea surface height improves the forecast skill of the model. The good comparisons between the model fields and observations as well as the skill of the forecasts allow to investigate the coupled mechanisms involved in the onset, development and termination of various events observed during the last decade. A special attention is drawn on the TOPEX/POSEIDON period.

ATMOSPHERIC FORCED VARIABILITY IN TERMS OF 3-D NORMAL MODE EXPANSION

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The aim of the present study is to analyse the field of forced variability of global atmospheric circulation, associated to oceanic forcing, based on an ensemble of ten independent long-term (ten-year) simulations by an AGCM. The model consists of an updated version of the spectral R-21 AGCM of the Melbourne University. Separation between internal and forced variabilities was performed based on a statistical definition of climate formulated in terms of ensemble means.
Analysis of internal and forced variability fields is performed by means of a 3-D normal mode expansion scheme, allowing a dynamically consistent separation of atmospheric scales of motion.
Obtained results demonstrate that the forced variability field may be adequately represented in terms of a reduced set of rotational modes, which may simplify the task of uncovering possible links between oceanic and atmospheric fields. Finally, different statistical measures of such couplings will be presented and discussed.

SIMULATION OF WINTER AND SUMMER MONSOONS OVER EAST ASIA WITH A NESTED GLOBAL-REGIONAL CLIMATE MODEL

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We use the recent versions of the community climate model (CCM3) and the regional climate model (RegCM2) developed at the National Center for Atmospheric Research (NCAR) to simulate both winter and summer monsoons over east Asia and to validate the new version's capability to produce basic characteristics of monsoon features over the region. For RegCM2 the vertical resolution is 16 levels and horizontal resolution is 90 km. The domain is centered at 100°E, 30°N and covers a 6,930 km × 7,020 km area encompassing eastern Asia (including Tibetan Plateau) and adjacent Pacific and Indian Ocean. The simulation periods are January and July. The initial and boundary conditions were obtained from CCM3 model integrations. The simulation patterns of monsoon transition, precipitation, land surface temperature are in general agreement with observations.

IMPACT OF INTERACTIVE ASIAN SUMMER MONSOON HEATING ON EL NIÑO/LA NIÑA FEATURES IN THE CANE-ZEBIAK COUPLED MODEL

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S. Nigam (Dept. of Meteorology, Univ of Maryland, College Park, MD 20742, USA)

The Asian summer monsoon heating anomalies are parameterized in terms of the concurrent Pacific-basin SST anomalies, and used as additional forcing in the global Gill-type atmospheric component model. The heating parameterization is developed from a rotated principal component analysis (RPCA) of *combined* interannual variability of the tropical Pacific basin SSTs, residually diagnosed diabatic heating at 400mb (from ECMWF's analyses), and the 1000mb winds; the combined RPCA technique itself is described in Nigam and Shen (1993).
A comparison of El Niño/La Niña populations in 50,000 years of the "control" and "monsoon" model integrations indicates that there are more strong El Niños and fewer weak ones in the "monsoon" run; likewise, strong (weak) La Niñas occur more (less) frequently in the "monsoon" run. The total number of ENSO events (all categories included) is however greater in the "monsoon" run, as also indicated by the power spectral density analysis, which shows enhanced power at the ENSO (and biennial) time-scale in the "monsoon" run.
A comparison of the composited El Niño SST evolution at the equator in the two model runs shows that the interactive Asian summer monsoon not only increases the El Niño SST amplitude (as expected from the positive feedback relationship between these two phenomena) but also leads to earlier El Niño termination — an improvement, given the longevity of El Niños in the original Cane-Zebiak model.

SEASONAL VARIATIONS IN UPPER TROPOSPHERIC WATER VAPOUR IN THE TROPICS MEASURED BY THE MICROWAVE LIMB SOUNDER ON UARS.

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W.G. Read (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California)

Water vapour in the upper troposphere has been measured by the Microwave Limb Sounder on the Upper Atmosphere Research Satellite (Read *et al.*, 1995). The measurements are centred on 215hPa and allow maps of relative humidity to be produced each day for the tropical region and beyond. In this paper, the observations have been analysed to reveal the timescale of variability in the tropics. Time-series of tropical observations at each longitude, show a strong annual cycle with maximum amplitude at longitude 30°E. Other cycles with periods of 48 and 77 days are evident near 160°E. The 48 day cycle appears to be associated with travelling disturbances which propagate eastwards with speeds of approximately 5° longitude day^{-1}. Studies aimed at relating these variations to other meteorological observations will be described.

VARIABILITY OF PRECIPITATION IN PORTUGAL ASSOCIATED WITH WEATHER CIRCULATION PATTERNS

J. Corte-Real, B. Qian and H. Xu (ICAT, Faculty of Sciences, University of Lisbon, 1700 Lisboa, Portugal)

Four major circulation patterns, associated with daily precipitation in Portugal, are classified from daily sea level pressure fields over the northeastern Atlantic and western Europe, based on k-means cluster analysis coupled with principal component analysis. A rainy pattern is well identified as well as two distinct dry patterns, one prevailing in summer and the other occurring frequently in winter; a blocking-like pattern with a probability of rain of 36.8% has also been identified. These patterns are quasi-stationary, normally persisting for one week and even for one month, especially the dry patterns. Interannual variations of monthly precipitation associated with the circulation patterns are also investigated. The results show that the variations of precipitation are coherent with the fluctuations of the frequencies of occurrence of both the rainy and the dry patterns. It is worth mentioning that the decreasing trend of March monthly rainfall in southern Portugal is related to the corresponding trends of the frequencies of both the rainy pattern and the summer dry pattern. The long term trend is not significant neither in other monthly rainfall sequences nor in the corresponding frequencies of circulation patterns. Besides, the long term variations in most months seem to be quasi-periodic. Singular spectrum analysis (SSA) is performed on these sequences to detect quasi-periodic oscillations. Relationships between oscillations in rainfall and in frequencies of circulation patterns, are also investigated.

LOW FREQUENCY OSCILLATIONS in FUTURE CLIMATE SCENARIOS

E. da Costa and J. Corte-Real (ICAT, Universidade de Lisboa, Campo Grande, 1700 Lisboa, Portugal)

Quasi-periodic interseasonal and interannual oscillations (QPO) within the North-Atlantic sector are isolated from a dataset of 240 years produced by three differents runs of the Hadley Center coupled ocean-atmosphere GCM: a control run with constant carbon dioxide concentration, a gradually increasing carbon dioxide simulation and a simulation with both carbon dioxide and sulphates aerosol forcings. The method used to indentify the QPO is the multichannel singular spectrum analysis (MSSA) which gives a rather complete space-time and spectral picture of the oscillating phenomena in a wide range of time and space scales.
The QPO simulated by the GCM compare reasonably well with those detected from observations, specifically, the 6 year, the 3.5 year and the 70 day oscillations. It is also found that the forcing effects due to carbon dioxide alone and CO2 plus sulphates do not modify neither the shape nor the amplitude of the detected oscillations.

INTERANNUAL VARIABILITY OF EUROPEAN MEDITERRANEAN CLIMATE USING A WEATHER TYPING APPROACH

C. C. DaCamara , J. G. Pinto and J. A. M. Corte-Real (ICAT, Faculty of Sciences, University of Lisbon, 1700 Lisboa, Portugal)

An objective method is used to classify large-scale atmospheric circulation affecting southern Europe in an appropriate set of Circulation Weather Types (CWT's). The method was applied to study CWT's over four different areas respectively located in Portugal (Alentejo), Spain (Guadalentin), Italy (Agri) and Greece (Lesvos).
Circulation affecting each area was characterised through use of a set of indices associated with the direction and vorticity of flow; indices are then used to classify circulation patterns into ten basic CWT's. A statistical treatment of frequency of CWT's was performed, involving analysis of intra- and interannual variability of CWT's. Some of the types (e.g., SW, E, W and cyclonic in Portugal) are related to moving cyclones towards the Mediterranean and others (e.g. cyclonic in Italy) reflect intense cyclonic activity over the cyclogenetic area of the Gulf of Genoa.
Correlation tests were also performed on a monthly basis between PC's of temperature/precipitation versus time series of relative frequency of CWT's. For instance, for Portugal it was found that W and SW types are highly correlated with PC1 of precipitation, except in the summer season; on the other hand, it is in that season that NE type is found to be highly related to the PC1 of temperature field, whereas W and NW types are highly anti correlated. Finally, a study is performed on long term variability of CWT's, an assessment being made of the impact of possible changes of the annual cycle of precipitation in the Mediterranean .

THE ROLE OF AN ACCURATE SST FORCING IN SEASONAL PREDICTABILITY OF TROPICAL PRECIPITATION

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The main source of predictability for tropical precipitation in the seasonal range comes from the sea surface temperature (SST) anomalies. Since these anomalies have a slow time evolution and thus a good persistence, it is perhaps not necessary to capture all the details with a good coupled model, at least during the first months of the forecast. Therefore we have carried out two series of numerical forecasting. In the first one, the SST is prescribed by the month by month observed values. This way is not compatible with real time forecast, but shows what the best ocean model could do. In the second series, the SST is calculated by an autoregressive scheme (a kind of optimal blend between persistence and climatology). Each series of forecasts consists of 30 4-month ensembles of 3 numerical predictions with a T42L31 version of the atmosphere model ARPEGE. The reduction of the skill in predicting the precipitation when using statistically predicted SST shows the potential of improvement for coupled models. However, the use of the statistical SST shows the feasibility of seasonal predictions in some tropical regions.

MODELLING SEASONAL RAINFALL VARIABILITY OVER SOUTH AMERICA USING A VARIABLE THRESHOLD TECHNIQUE

N.Dewhurst and M.Beaumont (University of Bristol, Centre for Remote Sensing, Department of Geography, Bristol, UK)

Early investigations of rainfall variability over Brazil through satellite modelling at the Centre of Remote Sensing (CRS) revealed that an infared threshold variation of 60k existed over the year of 1994 and that the threshold variation fluctuated dramatically. A more advanced technique has been developed at the CRS to produce small scale estimates of rainfall with geostationary satellite data, down to the resolution of the Meteosat (or other geostationary satellite) pixels. A threshold field technique has been adopted whereby threshold values are collated from infared temperatures and are optimised by the use of geostatistics. The optimum field is applied on a monthly basis, to provide maximum possible sensitivity to both the meteorology and the climatology of the area. This threshold field is then used to deal with problems such as local duration of cloud, suitable rain rate factors and provision of the model to take into the consideration the seasonal variations which are due to topography or climate. Research for the year of 1994 has produced positive results to understanding the complex variability which occurs both spatially and temporally over Brazil. Various rainfall regimes have been identified which allow the model to give accurate daily and longer rainfall totals. Frequent sampling has been found to be necessary because the temporal and/or spatial averaging help to subdue algorithm output noise and provide results which can compare well with rainfall variations sampled by ground observing stations

MONSOON CIRCULATIONS AND VARIABILITY: Sensitivity to Land Surface Parameterization Scheme and Orbital Perturbation.

B.-W. Dong and P. J. Valdes (Department of Meteorology, University of Reading, Reading RG6 6BB, UK)

The mean monsoon and its variability are analysed based on two 10 year AMIP simulations using the U.K. Universities' Global Atmospheric Modelling Programme (UGAMP) GCM with different surface parameterization schemes. The monsoon and ENSO relationship is observed in both simulations. Years with warm SST anomalies in the equatorial central and east Pacific have a weaker monsoon circulation, accompanied by lower than normal precipitation over Indian subcontinent, and vice versa. Intraseasonal variability of monsoon rainfall over India in weak and strong monsoon years is also studied in the two simulations, and its possible relationship with interannual variability is assessed. The changes of monsoon and its interannual variations due to orbital perturbation are also investigated in various palaeoclimate simulations using the same model.

ASIAN SUMMER MONSOON ONSET AND TIBETAN HIGH

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M.Cui (Institute of Oceanology, Chinese Academy of Sciences, 7 Nanhai Road, Qingdao 266071, China)

A climatology of some parameters of the Asian summer monsoon such as the onset and withdrawal date, duration, break, activity and rainfall is assembled from daily values of the ECMWF Re-Analyses dataset for 1979-1993.

A monsoon activity index is chosen as a diagnostic parameter to classify the monsoons into strong, weak and normal. Strong/weak monsoon years are characterised by composite anomaly maps of several variables.

The results show that the spring Tibetan high provides the most active forcing of the Asian summer monsoon since it controls the Indian summer monsoon onset as well as the northward advance of the East Asian summer monsoon onset. The activity index shows that the South Asian and East Asian monsoons are part of the same large-scale variation which makes a strong Indian monsoon coincide with low Meiyu precipitation (defined as weak monsoons according to the traditional methods in this region). The variations of the East Asian monsoon and the Indian monsoon appear to be generally reversed.

INITIAL ERROR GROWTH IN A HYBRID COUPLED MODEL OF ENSO USING SINGULAR VECTOR ANALYSIS

Ch. Eckert (Max-Planck-Institut fuer Meteorologie, Bundesstr. 55, D-20146 Hamburg, Germany)

Predictions of the state of ENSO with a forecast model depend on both the initial state and the uncertainty attributed to the latter. Therefore, the amplification of small initial errors over seasonal time scales in a Hybrid Coupled Model (HCM) of the tropical Pacific ocean-atmosphere system is investigated. The HCM consists of an ocean general circulation model coupled to a statistical atmosphere. Those spatial structures that exhibit the strongest growth over the forecast interval with respect to a prescribed norm, i.e. the leading singular vectors and values, are computed. This is accomplished with the assistance of an automatic differention tool acting on the numerical code to generate the linearisation of the HCM with respect to the forecast trajectory.

TIME SERIES ANALYSIS AND MULTI-SEASON PREDICTION OF ATLANTIC BASIN HURRICANE ACTIVITY

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A. A. Tsonis (Dept. of Geosciences, University of Wisconsin-Milwaukee, Milwaukee, WI 53201, USA)

Time series analysis using the singular spectrum approach (SSA) and maximum entropy method (MEM) reveals oscillatory behavior in the annual abundance of Atlantic basin hurricanes based on data from the past 111 years. SSA produces filtered time records that capture the dominant modes of hurricane variability; and MEM is useful in focusing on the particular frequencies in relatively noise-free records. Both approaches are linear but are data adaptive and thus perform well on short, noisy time series. Significant modes of hurricane variability occur at 2.5, 5.6, and 7.4 years. The high frequency oscillation reflects the well-established association of hurricane activity with the stratospheric quasi-biennial oscillation (QBO), while the semi-decadal oscillation is likely tied to the El Niño - Southern Oscillation (ENSO) of the Pacific basin, which has an irregular fluctuation in the range of 4 to 6 years. The semi-decadal oscillation is the most pronounced and explains nearly 40% of the detrended time series. The low frequency oscillation might be forced by sea surface temperature (SST) fluctuations in parts of the North Atlantic Ocean. Several methods are examined for exploiting these regularities toward the goal of making multi-season forecasts of Atlantic basin hurricane activity.

PREDICTION OF NINO3 SST ANOMALIES USING BAYESIAN OSCLLATION PATTERNS (BOP): AN UPDATE

RuizdeElvira, A. and OrtizBevia M., GezCeballos, C. (Universidad de Alcala de Henares, Alcala de Henares, Spain)

The statistical technique known as Bayesian Oscillation Patterns (BOP) had been applied to the analysis and prediction of ENSO. In particular Nino3 SST anomalies for 36 month, starting at each season from January 1963 to October 1983 have been forecastedf. The forecast skill was significant and very important for lead times up to 19 months. These results are extended in the present work, including the '80s and some of the '90s events

ENSO PREDICTION WITH AN IMPROVED INITILIZATION

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(*Space Science Dept., Rutherford Appleton Laboratory, Chilton Didcot, Oxfordsh. OX11 0QX, U.K.)
M.A. Balmaseda (ECMWF, Shinfield Park, Reading, RG2 9AX, U.K.)

Large-scale ocean-atmosphere interaction plays a crucial role in climate change and variability on a broad range of time scales. Prediction of future climate variations on timescales of months to a year depends on our ability to predict sea surface temperare (SST) in the tropics, particularly the tropical Pacific. As the information on which a forecast is based resides primarily in the ocean it is important to find the best initial state. Recently, through a series of modelling studies from an intermediate coupled ocean-atmosphere model, some improvements for ENSO prediction have been achieved. Using an improved assimilation procedure to achieve a better initial state, we can reduce the spring barrier. Further, based on past events for the 70 and 80s there was an indication of useful forecast skill(crelation of 0.6 or higher between observation and forecast) beyond one year. We also discussed the origin of well-known 'spring barrier' and the influence of extra-tropical processes on the SST prediction in tropical Pacific.

THE MADDEN-JULIAN OSCILLATION IN THE ECMWF REANALYSES AND IN THE ECHAM4 GENERAL CIRCULATION MODEL

S.Gualdi and A.Navarra (IMGA-CNR, Via Emilia Est 770, 41100, MODENA(MO), Italy)

The Madden-Julian Oscillation (MJO) is investigated in ECMWF reanalyses and in the ECHAM4 general circulation model (GCM), by means of the Principal Oscillation Patterns (POP) analysis. The modeling results are time series obtained from a simulation performed with the ECHAM4 GCM, at resolution T30 (triangular 30 waves) and with prescribed sea surface temperature form January 1961 to December 1994. The simulated MJO is compared with the MJO in the ECMWF reanalyses, using time series calculated from 4 times daily reanalyses from January 1979 to December 1989. In addition to the ECMWF reanalyses, a data set of observed outgoing longwave radiation (OLR) from NOAA are used to compute OLR composite patterns. To isolate the intraseasonal variability, a 15-90 day band-pass filter is used, whereas the seasonality of the MJO is highlighted stratifying the data by season. The MJO found in the reanalyses exhibits a marked seasonality in its occurrence with strongest activity in northern winter and spring. Evidences of an interaction between the MJO and the Indian summer monsoon are also found during northern summer. The model reproduces the seasonality of the oscillation, but only a moderate influence of the summer monsoon activity on the simulated MJO was found. The general features of the MJO simulated by ECHAM4 appear more realistic than those obtained with the previous versions of the ECHAM model.

THE EMPIRICAL MODEL OF CIRCULATION IN TROPICAL TROPOSPHERE DURING ENSO

Gushchina D.Yu., Semenov E.K., Meteorological department, Moscow State University, Moscow, Russia

On the ground of generalization of all aerosynoptic information available for last 3 dramatic ENSO events (1982-83, 1986-87, 1991-92) the empirical model of tropical atmosphere circulation under ENSO conditions was developed. In framework of this model the composite fields of principal circulation characteristics (vertical velocity, velocity potential and stream function) were plotted. The calculations are based on the mean monthly wind data received from NMC. The analysis of obtained results allowed to reproduce the picture of evolution of anomalous atmosphere circulation conditions typical for ENSO event. The new generalised scenario of ENSO evolution was created on the base of analysis of principal circulation parameters. This scenario can be considered as a new scheme of the event in terms of the change of ENSO characteristics since the beginning of 80-th. The fact that the principal ENSO associated anomalies were revealed even in the mean fields points to the common nature and stable evolution of the event. To elucidate the mechanism of ENSO associated circulation anomalies the spectral analysis of various meteorological parameters was carried out that allowed to estimate the contribution of various time-scale processes in the reorganization of basic circulation cells of low latitudes. To study the processes of initiation and relaxation of ENSO anomalies in terms of different time-scales processes activity the wavelet analysis of zonal and meridional wind was applied. The results of spectral and wavelet analysis showed the the different genesis of atmosphere circulation system anomalies during ENSO and allowed to make the suggestion that synoptic-scale processes can play an important role in the mechanism of ENSO onset. The work is supported by the Russian Foundation of Basic Researches.

SIMULATED INDIAN MONSOON VARIABILITY : ROLE OF SST AND INTERNAL DYNAMICS OF THE ATMOSPHERE

A. Harzallah and R. Sadourny (Laboratoire de Meteorologie Dynamique, Ecole Normale Superieure, Paris, F-75231 France)

We analyze relationships between the Indian summer monsoon and some atmospheric variables using Monte Carlo AGCM simulations. The focus is put on the distinction between relationships linked to SST variability and induced by internal dynamics of the atmosphere. We performed 16 Monte Carlo simulations with the LMD AGCM forced by observed SSTs for the period 1986-1989. The link between monsoon and the atmospheric variables is studied in terms of lagged correlations between monsoon anomalies and anomalies of the atmospheric variables forced by SSTs and resulting from internal dynamics. We found high correlations between the monsoon and atmospheric variables leading the monsoon by more than two seasons but only for the part of variability forced by SSTs. Lagged correlations indicate monsoon precursors two to three seasons earlier with patterns showing air warming, positive geopotential anomalies in the tropics and a SLP Indian ocean-eastern Pacific dipole. Upper air circulation resembles warm conditions during El Nino events. SST-forced Eurasia winter snow cover is also found as an important monsoon precursor. On the other hand, internally induced variability is strongly related to the monsoon only during the monsoon season. Well defined patterns are found with for example an Atlantic-Indian ocean SLP dipole. The implication for monsoon prediction is discussed.

TROPICAL CLIMATE PREDICTION

Stefan Hastenrath (Department of Atmospheric and Oceanic Sciences, University of Wisconsin-Madison, 1225 West Dayton Street, Madison WI 53706, USA)

A review is given of the current status of long-range forecasting in the low latitudes. Promising leads have been developed over the past five years in the seasonal forecasting for certain target regions of the tropics. Various approaches are of interest: (a) Empirical methods based on the combination of general circulation diagnostics and statistical techniques; (b) Numerical modeling, itself requiring also a diagnostic understanding from empirical analyses; and (c) Purely statistical techniques. Forecasts in real time are now being issued for various regions, mostly from methods combining general circulation diagnostics with statistics; numerical modeling is also being applied in real-time climate prediction for some targets. From this experience it seems most fruitful to pursue concurrently all three lines of approach. Remarkable spontaneous initiatives in diagnostic monitoring and prediction have been undertaken in various parts of the World, including documentation of methods and verification of performance. Publication of real-time forecasts in a recently established forecast forum stimulates the professional interaction. The cultivation of the essential databases in real time, including further improvement of quality control and timely availability, may be the most important communal task at this stage.

INTERACTION OF INTERANNUAL RAINFALL VARIABILITY IN WEST AFRICA WITH DECADAL AND SYNOPTIC SCALES

S. Janicot (Laboratoire de Météorologie Dynamique du CNRS, Ecole Polytechnique, 91128 Palaiseau cedex, France).

Interannual variability of West African rainfall is investigated on the last 50 years through observational datasets and modelling simulations. Two types of Sahel drought are pointed out, associated with different sea surface temperature (SST) anomaly patterns. The relationships between Sahel rainfall and SST have changed after 1970, resulting from a modulation by the global ocean decadal trend. In particular, the impact of the warm phase of El Nino / Southern Oscillation on Sahel drought appears stronger in the 70's and the 80's. At the synoptic and local scales, rainfall event occurrences in the Sahel have been shown to decrease on the last 50 years. The surface-land processes seem determinant to explain this negative trend. The role of easterly waves will be also suggested.

Interannual variability in NCEP coupled model and implication for ENSO prediction

M. Ji (NCEP/NOAA, W/NP24, Washington DC 20233 USA)
D. Wu and A. Leetmaa (NCEP/NOAA, W/NP24, Washington DC)

Principal oscillation pattern (POP) and singular spectrum analysis (SSA) methods were used to analyze zonal wind stress, SST and upper ocean heat content anomalies from NCEP coupled forecast model and observations. The results suggest that the model is capable of capturing the dominant seasonal to interannual oscillati on in the tropical Pacific associated with ENSO and this is the main reason that this model can predict ENSO with useful skill. The ENSO prediction skills of the NCEP coupled model for the 1981-1992 and 1992-1996 periods are significantly different with significantly lower skill for the later period. The reason for this is because of the dominant oscillatory characteristics for ENSO variability in the tropical Pacific during the 1990s is different than the canonical first POP mode. This is also supported by observational evidences. Examination of long-term sea-level records in the central equatorial Pacific show that the annual cycle in this region may not be a well defined, dominant variability, and there is evidence of significant interdecadal variability in the tropical Pacific. The interdecadal variability may have played an important role during the 1990s. The NCEP coupled model employs an anomaly coupling strategy which prevents the model from taking into account of interdecadal variability. Improvement in ENSO prediction skill will require development of fully coupled forecast model.

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AN ASSESSMENT OF THE TRANSIENT CONVECTIVE ACTIVITY IN THE UK MET. OFFICE GENERAL CIRCULATION MODEL.

C.G.Jones (CGAM, Department of Meteorology, University of Reading, Reading RG6 6AU, U.K.)

An assessment of the convective activity in 3 integrations of the UKMO General Circulation Model will be presented. The 3 model versions use identical physical parametrisations and dynamics and differ only in their respective horizontal and vertical resolutions. The 3 models were integrated over the period 1979-88 using monthly mean Sea Surface Temperatures as a lower boundary condition. The representation of convection, at interannual and seasonal timescales, will be presented and compared with AVHRR Outgoing Long wave radiation data. The sensitivity of convective activity and the associated water cycle to model vertical and horizontal resolution will be highlighted. An investigation of the response of convection and the tropical water cycle to large scale changes in the SSTs over this period will be presented.

ENSO Predictability with a Coupled Ocean-Atmosphere GCM

Ben Kirtman (Center for Ocean-Land-Atmosphere Studies, 4041 Powder Mill Road, Suite 302, Calverton, MD 20705 USA)

The Center for Ocean-Land Atmosphere Studies (COLA) anomaly coupled prediction system, using a sophisticated dynamical model of the tropical Pacific Ocean and the global atmosphere is described. The atmospheric component is a global spectral model with horizontal truncation at triangular wavenumber 30 and with 18 vertical levels. The ocean component is a Pacific basin model with 0.5° latitude and 1.5° longitude resolution in the equatorial wave guide and 20 vertical levels. Errors in the surface wind stress simulated by the atmospheric model are ameliorated by using the zonal wind anomalies at the top of the boundary layer. In developing ocean initial conditions for prediction experiments, an iterative procedure that assimilates the zonal wind stress based on the simulated sea surface temperature anomaly error is applied.

Using the prediction system, a large ensemble of "identical twin" experiments were made to estimate the limit of ENSO predictability. The dynamics and structure of initial error growth is analyzed in detail. The evolution of the initial error is consistent with the equilibrium response of the ocean model to stationary wind stress forcing. The predictability of ENSO as a function of the phase of ENSO is also examined. The predictability is largest during the transition from warm to cold or near normal conditions, whereas the predictability is relatively low during the transition from cold to warm conditions.

SIMULATION OF THE LOW FREQUENCY VARIABILITY OF THE MONSOON BY THE LMD AGCM

K. Laval and J. Polcher (Laboratoire de Meteorologie Dynamique, Ecole Normale Superieure, Paris, F-75231 France)

To study the Monsoon and its variability, we have performed integrations of the LMD Atmospheric Circulation Model (AGCM) for 10 years (AMIP runs) and we have analysed the low frequency variations of the Monsoon over India and South-East Asia. We have studied the relations between the low frequency variations and the northward propagation of the convergence zone and the rainfall. We have changed the surface conditions to examine the dependance of the variability of the Monsoon to surface conditions.

INTENSITY OF TROPICAL CYCLONES ORIGINATION AND LOCAL SUN'S ZENITH

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In the NW part of the Pacific Ocean tropical cyclones appear in the zones of the Western part of the North Passat current and in the South-China sea. Intensity maxima of these zones are localised in about 10 degrees in latitude and longitude. The more intense, by the number of generated in the summer period cyclones, are the following 3 regions: near the maxima depths of the Marianas trough, the Philippines trough, and South-China sea. Cyclogenesis in the Philippines and South-China seas exhibit seasonal variability of mean latitude origination and cyclone intensity. In august the more intense cyclone generation is found near latitude 20-21 degree N. The seasonal variability of cyclone origination over latitude correlates with latitude movement of Sun's zenith (with the correlation coefficient about 0.85). Maximum of the cyclone origination sites distribution over latitude is in delay about 1.5 months of Sun's zenith position. We expect that similar results can be obtained also for all other regions of intense cyclone generation. On the other hand, analysing the effects of charged particle precipitation (under the influence of Solar activity) from the Earth's radiation belts it was shown that there exists partial correlation with the type (latitudinal/zonal) of cyclone track.

ENSEMBLE ATMOSPHERIC GCM SIMULATION OF CLIMATE INTERANNUAL VARIABILITY FROM 1979 TO 1994

Z.-X. Li (Laboratoire de Météorologie Dynamique du CNRS, 24 rue Lhomond, 75231 Paris cedex 05)

The climate interannual variability is examined using the General Circulation Model (GCM) developed at LMD in Paris. The model is forced by the observed sea-surface temperature for the period 1979-94. An ensemble of eight simulations is realized with different initial conditions. It is shown that, except for the equatorial strip, the internal model variability is larger than the external variability. The ensemble mean is thus necessary in order to focus on the model's response to external sea-surface-temperature anomalies. The variation of the Southern Oscillation is studied. The simulated sea-level-pressure anomalies at both Tahiti and Darwin are realistic compared to observation. In a more general manner, the correlation map between the sea-level pressure and the Niño-3 sea-surface-temperature index reveals a well developed dipole structure over Pacific and the Indian Ocean. Associated with the variation of the Southern Oscillation, the precipitation, outgoing longwave radiation, surface-wind stress and surface energy flux over equatorial Pacific show large modulations. A global El Niño pattern index is defined and calculated for both the simulation and the NCEP re-analysis data. A good agreement is obtained, although the main contribution to the good agreement comes from the Tropics.

ASIAN MONSOON SIMULATED BY A VARIABLE HORIZONTAL RESOLUTION GLOBAL CIRCULATION MODEL

V.LORANT and J.F.ROYER (Meteo France,CNRM, 42 Av. Coriolis, Toulouse, France)

A detailed study of the monsoon's synoptic systems could help us understand the different phases of the Asian monsoon. Although improvements have been made in the ability of climate models to simulate regional scales, a stretched grid general circulation model appears to be an interesting option in order to simulate the dynamics of the monsoon, especially over the Bay of Bengal. This stretched version of the ARPEGE Climat GCM employs a horizontal grid that decreases monotonically in both directions (longitude and latitude), from the pole to the antipode, such that grid cells covering the Bay of Bengal are 55km wide whereas grid cells covering the eastern tropical Pacific are more than 500km wide. The ability of the model to simulate the Asian summer monsoon has been validated. The ability of the model to simulate formation, track, intensity and phase of the low pressure systems that develop in the Bay of Bengal and northwestwards onto the subcontinent will be presented.

ANALYSIS OF BLOCKING TYPE CIRCULATION OVER EUROPEAN-ATLANTIC REGION IN CONNECTION WITH SST FROM TROPICAL ATLANTIC

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For the monthly values of 500 hPa height (1965 - 1987), a blocking type index (I_B) has been calculated for the European-Atlantic (EA) region (50^0W - 40^0E ; 35^0N - 65^0N). For the same period SST from tropical Atlantic, have been analysed by EOFs. For each month, the correlation between I_B and SST has been tested, using SST filtered by first 5 EOFs and more components (for which associated eigenvalues >1), with the lag between 1 and 12 months. In this way, the significant teleconnections have been found and for the each month pair, the key zones from the tropical Atlantic have been determined. The good results exist for I_B in February in connection with SST in October and November. Finally, the capability of the time - slice experiments performed at DKRZ Hamburg to reproduce the blocking circulation is discussed. In comparison with the observations, the control experiments reproduce well the blocking circulation in February, July , August , September and October, while $2*CO_2$ and $3*CO_2$ experiments lead to a decrease of this type of circulation in August and October.

SENSITIVITY STUDY OF THE EFFECTS OF GLOBAL SEA SURFACE TEMPERATURE CHANGES ON THE ASIAN SUMMER MONSOON

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The Asian summer monsoon circulation is an important component of the global general circulation. There is also increasing evidence that monsoon variability is related to the interannual behaviour of the El Nino - Southern Oscillation (ENSO) in the Pacific Ocean. The manner in which the large scale sea surface temperature (SST) anomalies affect the monsoon, and how the monsoon influences ENSO, are not yet fully understood. Here, we carry out a simple sensitivity study using the UK Meteorological Office Unified Model, initialised on 1st December 1992 and run for 13 months. Climatological SSTs are used, and a fixed idealized El Nino SST anomaly is added throughout the year. This results in a reduction in the total monsoon rainfall over India, and a delayed and more gradual onset compared with the control run. Applying the fixed anomaly at different times of the year, for example, only during the months prior to the monsoon season (December to April inclusive), or only during the monsoon season (May to October inclusive) allows the sensitivity of both the strength and the duration of the monsoon to global SST variations to be assessed. The results will be reported on at the meeting.

EQUATORIAL LOWER STRATOSPHERIC QUASI-BIENNIAL OSCILLATIONS: TENDENCIES OF CHANGE

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An analysis of the equatorial lower stratospheric (ELS) zonal wind and temperature quasi-biennial oscillations (QBOs) with the help of the method of cycles (including analysis of the phase portraits evolution) is performed. The data for last few decades are used. It is found that the ELS QBO amplitude is positively correlated with its period. This relationship is strongest in the 20-15 mb layer and at the 70 mb level but weakest - in the 50-30 mb layer. Both period and amplitude of the ELS QBO show a general general upward trend during last 40 years in the 20-15 mb layer. The latter is in a general agreement with tendencies of temperature annual mean values and annual cycle (AC) change. Possible connection of the ELS QBO changes with the other characteristics of climate variability is discussed. The ability of different mechanisms of the QBO generation to display the positive correlation between the QBO amplitude and period are examined. In particular, the model of the Holton-Lindzen type and mechanism of the QBO generation by parametric resounance due to temperature AC are analyzed. Influence of variations of radiative-active components (including carbon dioxide, ozone, water vapour and volcanic and/or anthropogenic aerosol) in the atmosphere on the ELS QBO amplitude and period tendencies of change is discussed.

SKILL AND REPRODUCIBILITY OF SEASONAL RAINFALL PATTERNS OVER TROPICAL AMERICA IN GCM SIMULATIONS WITH PRESCRIBED SST

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The ECHAM-4 atmospheric general circulation model (GCM) has been integrated at T30 resolution through the period 1960-1994 forced with the observed sea surface temperatures (SSTs) as compiled at the Hadley Center. Three experiments, differing only by initial conditions have been made. The capability of the model to reproduce realistic observed climatic variability (= skill) and quantity of the interannual variability which is independent from initial conditions (= reproducibility) in rainfall fields were estimated using Singular Value Decomposition analyses between observed and model fields (OM) and amongst the different model runs (MM). It is found that skill and reproducibility are linked in a quasi-linear fashion and that the model mode with strongest reproducibility is also the mode which verifies best with observations. The most skilful and reproducible mode is strongly related to the Southern Oscillation Index (SOI) in October-December (tropical America) and December-March (southern tropical America). A substantial component of the interannual variability is independent from the SOI in March-May (tropical America) and July-September (northern tropical America) when Atlantic SST are strongly related to the leading mode of OM and MM analyses.

INTERANNUAL VARIABILITY OF THE ASIAN SUMMER MONSOON IN AN ENSEMBLE OF MULTIDECADAL SIMULATIONS WITH UKMO CLIMATE MODEL

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D. P. Rowell (Hadley Centre for Climate Prediction and Research, Bracknell, UK)

The potential predictability of the regional and large scale interannual variability of the Asian Summer Monsoon has been evaluated using a 4-member ensemble of 45 year integrations with the UKMO Unified Model (UM). Each integration was forced with observed SSTs (GISST) for 1949-93. The dominant modes of the monsoon's interannual and intraseasonal variability have been computed and the relationship between them has been studied. The influence of the Asian Summer Monsoon on the climate of the eastern Mediterranean, as simulated by the UM, will be described.

THE INDIVIDUAL TROPICAL CYCLONE GENESIS POTENTIAL

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The daily cyclone genesis potential and individual tropical cyclone genesis potential are calculated for a number of geographical regions of tropical cyclone formation on the base of wind fields of the European Centre for Medium Range Weather Forecasts. It is shown that the individual tropical cyclone genesis potential which takes into account both the large-scale relative vorticity and large-scale horizontal divergence is more sensitive characteristics for the estimation of tropical cyclone evolution. The maximum of individual tropical cyclon genesis potential is on the average one day ahead of the pressure minimum in the tropical cyclone center. Thus individual tropical cyclone genesis potential could serve as a predictor of development of tropical depression into tropical storms.

THE REPRESENTATION OF TROPICAL CYCLONES IN A CLIMATE RUN WITH THE HADLEY CENTRE GCM AT HIGH RESOLUTION

V. Pope, H. Maclean and R. A. Stratton (Hadley Centre, UK Met Office, London Rd. Bracknell, RG12 2SZ, England)

General Circulation Models used to simulate climate do not have adequate resolution to represent hurricanes properly. They do resolve some sort of large-scale tropical cyclones, however. The representation of these cyclones is considerably improved in models of higher horizontal resolution. This paper compares tropical cyclones in two AMIP integrations run with the Hadley Centre GCM, HADAM2b. The first is at high resolution (0.833 x 1.25 deg) the resolution currently used in the UK Met Office operational forecast model. The second is at standard resolution (2.5 x 3.75 deg), the resolution generally used for climate simulations. The results are compared with data from the ECMWF reanalyses and with climatologies of tropical storms. Seasonal, geographical and interannual variability of cyclone tracks will be diagnosed. The structure of individual storms will be described.

SEASONAL VARIABILITY OF SURFACE TEMPERATURE IN PORTUGAL

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C. C. DaCamara (Dept. of Physics, University of Lisbon, 1700 Lisboa, Portugal)

An analysis is performed on time and space variability of fields of surface temperature in Portugal as well as of sea-level pressure (SLP) and 500 hPa geopotential (Z500) over North Atlantic and Western Europe, covering a 34-year period, from June 1955 until May 1989.
A Principal Component Analysis (PCA) was performed on each of the fields and obtained spatial patterns showed to be in agreement with results from synoptic experience and climatology.
With the aim of relating variability of temperature field with the most prominent characteristics of large-scale circulation fields, Singular Value Decomposition (SVD) and Canonical Correlation Analysis (CCA) was also performed, leading to the identification of patterns of coupling between temperature and SLP/Z500 fields.
Finally, a statistical model was developed, based on correlation between PC1 of temperature (that explains most of seasonal and non-seasonal variability) and leading principal components of circulation fields (Z500 and SLP). Obtained results, that lay the grounds for a statistical model of long-range forecasting of surface temperature in Portugal, will be presented and discussed.

SPATIAL AND TEMPORAL VARIABILITY OF THE SEASONAL CYCLE IN CLIMATOLOGICAL PARAMETERS OVER THE NORTHERN HEMISPHERE

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Climate variability at decadal to interdecadal time scales can be expected to affect the seasonal cycle in climatological parameters with characteristic spatial patterns. Global data sets for the last 200 years of monthly means of relevant parameters such as air pressure, temperature, precipitation and sea level are generally biased towards the Northern Hemisphere and recent decades. Therefore, the analysis of the seasonal cycle is restricted here to the Northern Hemisphere. For each parameter, sequences of geographic maps of the seasonal cycle are constructed for subsequent time intervals. These maps reveal distinct spatial variations of the seasonal cycle. E.g., in North Atlantic air pressure the transitions from land to ocean are characterised at the western boundary by smooth variations of the seasonal cycle and at the eastern boundary by phase changes of 180° over a narrow ($\approx$ 100 km wide) zone following approximately the coast line. For each investigated parameter, significant temporal variations of the seasonal cycle are found in both amplitude and phase. These variations are spatially coherent with the largest temporal changes generally close to the boundaries of climate domains. E.g., in air pressure the largest variations are found close to the transition zone at the eastern boundary of the North Atlantic. Detecting temporal variations in such small-scale spatial patterns of the seasonal cycle requires climatological data sets with high spatial resolution.

SEA SURFACE TEMPERATURE FORCED INTERANNUAL VARIABILITY OF TEMPERATURE AND PRECIPITATION OVER EUROPE

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In this study we investigate external (i.e. SST forced) interannual variability of surface air temperature and precipitation over Europe during winter (DJF) and summer (JJA). This study is based on an ensemble of ten 10-year long simulations with prescribed AMIP SSTs and sea-ice coverage generated by the Melbourne University General Circulation Model (MUGCM). Each of the 10 simulations started from different initial conditions randomly obtained from an earlier 30-year control simulation. The MUGCM is a 21-wave spectral atmospheric model with nine vertical sigma levels. Radiation in allowed to interact with carbon dioxide, ozone, water vapour and clouds, whose spatial and seasonal distributions are prescribed to their climatological values. Results shows that external forcing of both variables considered can account for more 20 % of their total variance in some regions. Their spatial patterns are coherent over large areas of Europe.

SENSITIVITY OF A GLOBAL COUPLED OCEAN/ATMOSPHERE MODEL TO SEASONAL INITIAL CONDITIONS

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In the perspective of using global coupled ocean/atmosphere models to perform seasonal climate prediction, five experiments coupling the ARPEGE1 atmosphere and the OPA7 ocean models through the OASIS coupler have been run. Initial conditions for both models are taken from a forced experiment used as a reference trajectory. Coupled experiments start every three month from January 1992 to January 1993.
The ocean behaviour just after coupling (i.e. when a shock is produced by the inadequacy of the interface fluxes) is described in a few key regions. It is found systematically the same in the tropics, and strongly interacts with the seasonal cycle. In the Gulf Stream region, the shock can have two distinct effects, leading to two different situations, depending whether coupling occurs in January or not.
Global indices are used to quantify divergence between forced and coupled experiments. It is found that spring is a period when the coupled trajectory diverge quickly, suggesting that a fundamental coupled processus exist that can not be reproduced when ocean and atmosphere do not adjust interactively. It is shown that the location for this processus is preferably in the tropical atmosphere and that it propagates downward into the ocean.

SCHUMANN RESONANCE OBSERVATIONS IN CENTRAL EUROPE AND THEIR GLOBAL TROPICAL TEMPERATURE RELATIONS

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The electromagnetic eigenfrequencies of the Earth-ionosphere cavity are called Schumann resonances (SR). The excitation source of the cavity is the global lightning activity. Williams [1992] suggested that SR can be used as a global tropical "thermometer", based on the observation that the lightning activity is very sensitive to small temperature variations. The semiannual variations of SR intensity and frequency range measured in the vertical electric component at the Nagycenk Observatory (47.6°N, 16.7°E) is the manifestation of the semiannual variation of the surface air temperature in the tropical continental regions. The latter is due to the semiannual wave of solar insolation with maxima at equinoxes. The magnitude of the semiannual wet-bulb temperature variations in the tropical region is about 1.0-1.5°C [Williams,1994]. The quality of this SR data set makes it suitable for indicating temperature variations at the level of some tenths degree centigrade. This is demonstrated by the anomalous behaviour of SR parameters in December 1995 due to a simultaneous small temperature increase in the South American tropical region, as compared with the previous December.

SEA WARMING AS A DOMINANT FACTOR BEHIND NEAR-RECORD ATLANTIC HURRICANE ACTIVITY

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Tropical cyclones rank above earthquakes as the major geophysical cause of loss of life and property. Years with high numbers of hurricanes provide new insight on the environmental factors influencing interannual variability; hence the interest in the exceptional 1995 Atlantic season which saw 11 hurricanes and a total of 19 tropical storms, double the 50-year average. Current thinking associates seasonal changes in Atlantic hurricane frequency with subtle shifts in atmospheric large-scale circulation. We show that another factor, the sea surface temperature (SST) in the 10°-20°N, 20°-60°W region where most of the 1995 hurricanes developed, was the dominant environmental influence behind the 1995 near-record activity. During the 3-month August-October peak in activity, this SST experienced record warm levels, 0.66°C above the 1946-1995 mean. It explains 61±34% of the 1995 anomalous activity to 95% confidence. We suggest a physical basis for the SST influence in terms of the additional energy it provides in raising the trade-wind temperature inversion, thereby permitting more of the 3-5 day repetitive easterly wave initiating disturbances to grow into hurricanes.

INFLUENCE OF LAND-ATMOSPHERE INTERACTIONS AND SST ANOMALIES ON THE INTRASEASONAL VARIABILITY OF THE ASIAN SUMMER MONSOON: A GCM STUDY

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L. Ferranti (European Centre for Medium-Range Weather Forecasts, Reading, UK.)

Using the UKMO climate model, a series of sensitivity experiments have been performed to understand the influence of land-atmosphere interaction and SST anomalies on the intraseasonal variability (ISV) of the Asian Summer Monsoon. The model is integrated in perpetual July mode to obtain statistically robust results on the dominant modes of ISV, the probability of being in one regime or another, and the regime residence times. The results from experiments with interactive and fixed soil hydrology will be described. The impact of an idealized El Niño on the behaviour of the ISV has also been investigated. The results will be compared with similar experimentation with the ECMWF IFS model. The implication of the results for the potential predictability of the monsoon will be discussed.

ON THE MAINTENANCE AND INITIATION OF THE INTRASEASONAL OSCILLATION: A COUPLED OCEAN-ATMOSPHERE PHENOMENON?

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Examination of the latent heat flux from the NCEP/NCAR reanalysis suggests that evaporative wind feedback and frictional wave-CISK (conditional instability of the second-kind) are not the dominant mechanisms for promoting the eastward propagation of the intraseasonal oscillation since evaporation to the west of the convection dominates. The initiation of convection over the Indian Ocean occurs over warm sea-surface temperature (SST) anomalies. There is a systematic association between convection, SST and latent heat flux that appears to modulate the eastward propagation of the intraseasonal oscillation over the Indian Ocean and western Pacific. To the east of the convection, where subsidence occurs, warm SST anomalies develop. Subsequently, these locations are the preferred sites for the development of convection, and the convective envelope expands eastward. Decreasing SSTs near the western portion of the convective envelope are associated with the enhanced latent heat flux (and possibly cloud shielding), and are linked to the cessation of convection. Thus, it appears the intraseasonal oscillation should be treated as a coupled air/sea mode. The data suggest precursory signals in the Atlantic Ocean are present prior to the initiation of convection in the eastern hemisphere. These signals may be useful for medium-range prediction.

MONITORING THE TROPOSPHERIC TEMPERATURE BY MEANS OF A GENERAL CIRCULATION MODEL

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The recent global tropospheric temperature trend can be reproduced by climate models that are forced only by observed sea surface temperature (SST) anomalies. In this presentation, simulations with the Hamburg climate model ECHAM are compared to temperature soundings from satellites (MSU) and to the recently completed ECMWF reanalyses.
There is remarkable overall agreement of observed and simulated tropospheric temperature anomalies in many regions, in particular in the tropics and over the oceans, which lack conventional observing systems. This gives the perspective to link physically different quantities, such as surface observations or analyses (SST) and satellite soundings (MSU) by means of general circulation models.
The method can indicate inconsistencies between MSU temperatures and SSTs and has apparently done so. Differences between observed and simulated tropospheric temperature anomalies can partly be attributed to stratospheric aerosol variations due to major volcanic eruptions.

INTERANNUAL VARIABILITY OF THE SEASONS

D. B. Stephenson (Météo-France, 42 Av. Coriolis, Toulouse)

The seasons are the complex non-linear response of the terrestrial climate system to the regular annual solar forcing and there is no *a priori* reason why they should remain invariant from year to year, as is often assumed in climate studies when extracting the annual cycle. The econometric X-11 seasonal adjustment procedure takes account of changing seasonal shape, and thus allows one to extract an interannually varying annual cycle and thereby study its interannual variations. The method will be demonstrated using some well-known examples such as the Niño-3 sea surface temperature index, the Mauna Loa CO_2 time series, and the AVHRR satellite observed outgoing longwave radiation from 1974-94.

The Sensitivity of the Indian Summer Monsoon to changes in Orography.

P.J. Valdes (Department of Meteorology, University of Reading, Earley Gate, Whiteknights, Reading. UK)

A number of sensitivity experiments have been performed to investigate the role of orography in the Indian Summer Monsoon, using the UGAMP GCM. Both the Tibetan and East African orography have been removed and the resulting changes in the intensity, and seasonal evolution of the monsoon have been studied. The role of Tibet is as expected, in that removing Tibetan orography considerably weakens the monsoon. However changing the East African orography is more complicated. It changes the circulation over the Indian ocean resulting in an eastward movement of the monsoon, but no significant change in intensity.

A POSSIBLE INITIATION MECHANISM FOR THE TROPICAL INTRASEASONAL OSCILLATION

Gui-Ying Yang and Brian J. Hoskins (Dept. of Meteorology, University of Reading, Earley Gate, PO Box 243, Reading, RG6 6BB, U.K.)

A possible trigger mechanism for the tropical intraseasonal oscillation (TIO) is studied using an analytic Gill-type model and a baroclinic model with oscillatory forcing. The results show that local subtropical or extratropical vorticity/heating forcing with positive frequency, corresponding to eastward propagation, can trigger deep vertical motion on the equator with a zonal scale much larger than that of the forcing itself and magnitude comparable to that in the forcing region. The response is basically characterised by the Kelvin wave and has a very deep vertical structure. There are associated maxima in T' and u'. Baroclinic model experiments with a realistic DJF zonally asymmetric flow indicate that a local extratropical forcing near 0°E gives a maximum vertical motion response on the equator, this occurring over Africa and into the Indian Ocean, consistent with where the TIO convection appears to become organised. It is shown that the crucial part of the asymmetric response is associated with the upper tropospheric tropical zonal flow. This study suggests that eastward moving extratropical wave trains from Europe may play an important role in the initiation of the TIO.

CLIMATE CHANGE ALONG UNIVERSAL ROUTES TO CHAOS?

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Peter Carl (Institute of Physics, Humboldt University at Berlin, Germany)

Detection and attribution to causes of changes in the climate system are crucially dependant upon understanding the very nature of its reference state. Conceptions of dynamic systems theory have proven their effectiveness in recent attempts to characterize the system's current status and potential routes of change. These include efforts to clarify the dynamic origin of El Nino / Southern Oscillation (SO) using intermediate coupled atmosphere-ocean models and to answer queries about the nature of the annual cycle (AC) that derive from dynamic features of the atmosphere-land system. Substantiated by systems analytic studies using a General Circulation Model, the planetary scale monsoon to which a central role in these dynamics is assigned has been traced to follow its own universal routes to chaos. Moreover, monsoon dynamics is found intimately connected with both leading interannual modes. Using insolat ion changes of historical and paleoclimatic relevance as prototype forcings, this paper focusses on the delicate role that these mechanisms appear to play in view of internal climate variability and response to external forcing. Jumps in phase space due to changes in the synchronization of planetary waves indicate that the system's intraseasonal organization does not appear to support the idea of a unidirectional response to forcing trends. This is confirmed by seasonal integrations using percent-scale steps in insolation.

ROLE OF SALINITY IN OCEAN ATMOSPHERE INTERACTIONS IN THE WESTERN PACIFIC

J. Vialard and P. Delecluse (Laboratoire d'Océanographie Dynamique et de Climatologie)

Lukas and Lindstrom (1991) suggested that salinity stratification in the subsurface layer of the western Pacific warm pool might have an important effect in cutting off the oceanic vertical heat fluxes ("barrier layer" effect). In the equatorial region, OGCM simulations suggest that barrier layer formation is linked to a salinity front arising from the large scale zonal convergence between central Pacific salty water and western Pacific fresh water. The impact of this barrier layer on the physics of the "fresh pool" is evaluated by using sensitivity experiments. Salinity stratification influences the heat budget of the surface layer: thick barrier layers result in cutting down the entrainment cooling of the upper ocean. Mixed layer depth in the western Pacific is strongly limited by haline stratification. The wind stress is thus trapped in the surface layer by haline stratification, resulting in a strong sheared jet response to westerly wind bursts. The effect of atmospheric synoptic activity on barrier layer dynamics is then explored. In the forcing region, a wind burst destroys the barrier layer, when it is not associated to heavy rain conditions. Meanwhile, remote forcing influences barrier layer formation by modifying the zonal current structure in the frontal region. A wind burst eventually results in an eastward shift of the barrier layer region, where the air sea interactions are strong. By amplifying the surface layer response to atmospheric forcing and switching on and off the entrainment cooling of the surface layer, salinity might play an important role in the ENSO onset and development.

OA23 Climate variability: observations and modelling

03 Decadal variability: North Atlantic and Arctic climate

Convener: Latif, M.
Co-Convener: Navarra, A.

DECADAL CHANGES OF THE BLACK SEA HYDROGRAPHIC FIELDS

Belokopytov, V.N., A.B.Polonsky and B.A.Yurchuk (Marine Hydrophysical Institute, Sevastopol, 2 Kapitanskaya St., Ukraine)

The aim of this paper is to study the decadal variability of hydrographic fields in the northern part of the Black Sea and its possible reasons.We used the monthly sea level pressure, latitude and longitude of Azor High and Iceland Low, hydrographic Black Sea data sets for 1924 to 1994. Up to 60% of total variance of all analyzed hydrographic parameters are due to decadal to interdecadal variability. Low-frequency variability of the hydrographic fields occurs concurrently over the North Black Sea. This is induced mostly by low-frequency variability of the atmospheric circulation and associated changes of the Black Sea river discharges. When winter atmospheric circulation over the North Atlantic intensifies, the Azor High / Iceland Low shifts to the North-East, Danube discharge drops. On the contrary precipitation over the Black Sea rises due to enhanced activity of the Mediterranean cyclones. This leads to changes of the hydrographic fields on the decadal scale.

LINKING SUBTROPICAL DEEP WATER CLIMATE SIGNALS TO NORTH ATLANTIC SUBPOLAR CONVECTION VARIABILITY

R.G. Curry and M.S. McCartney (Department of Physical Oceanography, Woods Hole Oceanographic Institution, MS 21, Woods Hole MA 02543 USA)

We establish a geographic and temporal context for a portion of the warming trend reported at mid-depths in the North Atlantic subtropical basins over the past 50 years. Patterns of changes in the Upper North Atlantic Deep Water (UNADW). 1) The long-term warming actually involves decadal oscillations of warming and cooling episodes. 2) These patterns show a strong time-delayed correlation to waxing and waning subpolar convection that modulates the volume of Labrador Sea Water (LSW) entering the subtropics. The cold, fresh LSW mixes with warm, salty Mediterranean Outflow Water (MOW) to produce UNADW with characteristics intermediate to the sources. A decrease in the LSW component causes a relative ascendancy of the MOW characteristics and results in a warmer, saltier, and thinner UNADW layer. Conversely, an increase in LSW entering the subtropics results in fresher, cooler, and thicker UNADW. 3) The patterns further suggest that the long-term UNADW warming is about to come to a dramatic end as a tremendous plume of LSW, which convected to extreme thicknesses from 1988 to 1995 is now invading the subtropics. From historical observations, we estimate about a six year time delay for a subpolar signal to reach Bermuda, and slightly longer for the signal to propagate south of 30N in the western basin. 4) Finally we note the impact of the subpolar thickness signals on the flow along the subpolar/subtropical gyre boundary and its possible feedback to the intensity of the Gulf Stream and North Atlantic Current as M. Spall has modelled.

WEATHER OBSERVATIONS IN LUND, SOUTHERN SWEDEN, 1740-1860

C. Achberger and M. Ekstrom (Department of Physical Geography, Lund University, Solvegatan 13, S-223 62 Lund, Sweden).

In Lund, instrument observations have been made regularly since 1740. Air pressure and temperature, wind strength and direction, cloudiness and general weather observations were generally recorded three times a day. The pressure series is the most complete and reliable; only 1% of the total number of observations are lacking. Daily observations of air pressure and temperature were digitised manually from hand-written manuscripts within the European ADVICE-project covering the period between 1780 and 1860. The station history has been compiled from various primary sources, providing information about instruments, observers, movements and changes of instruments as well as general descriptions of the observation site. Instruments were moved several times, but always within a radius of about 300 m inside the city centre. All sites were located at an altitude of 34-61 m a. m. s. l. The early pressure data set has been corrected for changes of the station in altitude, varying observation times and has been reduced to sea-level pressure. We plan to link the early pressure observations to the modern pressure series (after 1860), to ultimately create a complete series of daily observations until present.

THE NORTH ATLANTIC OSCILLATION IN ATMOSPHERE AND OCEAN

R.G. Curry and M.S. McCartney (Department of Physical Oceanography, Woods Hole Oceanographic Institution, MS 21, Woods Hole MA 02543 USA)

The North Atlantic Oscillation (NAO) exhibits decadal/interdecadal variability. We focus on the last 50 years, characterized by a decline from high NAO index in the late 1940's to a low index in the late 1960's, and a recovery to high index by the early 1990's. The epoch of declining NAO was characterized by warm SST, especially in winter, compared to the years of increasing NAO index. These warm and cold epochs involved the slow movement of warm/cold winter SST anomalies cyclonically around the subpolar gyre, a manifestation of heat anomalies in the deep winter mixed layers, also referred to as subpolar mode water (SPMW). The agent of northern North Atlantic transformation of warm water to cold, the SPMW pipeline thus ran warm and cold during these epochs, as did the end product of this transformation, the deep-convecting Labrador Sea Water (LSW). Concurrently with these epochs of waning/waxing NAO and warming/cooling SPMW and LSW, we find a weakening/strengthening of the eastward flow along the subpolar- subtropical gyre/gyre boundary associated with the relative strength of warm water advection into the subpolar transformation pipeline. The sum of this evidence suggests a possible oceanic trigger for the transition between high and low NAO epochs: heat anomalies generated by intensified/weakened flow along the gyre/gyre boundary are injected into the SPMW transformation pipeline which retains the memory of the anomalies over several years, and annually re-exposes them to the atmosphere. Perhaps this drives the overlying sea-level pressure variability of the decadal/interdecadal NAO?

SPATIAL AND TEMPORAL CLUSTERS OF THE DECADAL VARIABILITY OF SEA SURFACE TEMPERATURE, WIND SPEED AND SEA LEVEL PRESSURE FOR THE NORTH ATLANTIC.

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Spatial and temporal patterns of the decadal variability of sea surface temperature (SST), sea level pressure (SLP) and near-surface wind speed for the North Atlantic were computed using COADS archive and cluster analysis. Sequence of typical patterns and their interdependence were traced for last 40 years. Correlations between SST, SLP and wind speed anomalies on the decadal time scales in this approximation are following from geostrophical balance. Partitioning of the North Atlantic using temporal clusters revealed more small-scale structures in the SST anomalies connected with known oscillation like NAO and more long-distance teleconnections. Among latter, the confirmation of the conveyor belt mechanism for the Atlantic Ocean is received. A difference between the Atlantic and Pacific is discussed

MAXIMUM AND MINIMUM TEMPERATURES VARIATIONS IN ANDALUSIA DURING THE LAST CENTURY

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In this work, long records of maximum and minimum temperatures corresponding to several places in Andalusia have been analysed in order to establish significant fluctuations and long trends. These variables have an important role in the climate of Andalusia, caracterizated by mild winters and very warm summers. On the other hand, Andalusia is located in a interesting place from the climatic point of view, between two great seas and continents and in the circumpolar vortice border. Work in progress suggests a general and similar increase of both temperatures, a different behaviour of that found for other researchers for other places. Both temperatures seem to show similar decadal fluctuations. However they seem to be related with atmospheric circulation changes in a diferent way.

CHANGES OF RAINFALL IN ANDALUSIA SINCE LAST CENTURY

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In this work, we analyze the long trends and changes of the annual and seasonal precipitation in Andalusia (Southern Spain). This area has a particular interest from the climatic point of view, due to their geographical position and the bad, or at least, unclear GMSs predictions for this variable in the Southern Europe. Preliminary results suggest a temporal coherence for all the region, with decresing trend for annual records, mainly connected with the decrease of spring rainfalls. It is possible to distinguish periods with prevaling dry/humid coditions. Major of these decadal fluctuations can be related with changes of atmospheric circulation over the area.

THEORY AND MODELING OF DECADAL CLIMATE VARIABILITY

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The integral response of the midlatitude ocean to stochastic atmospheric forcing is discussed and compared to observations and coupled GCM results. In the surface mixed layer, the random walk oceanic response is primarily local and limited by oceanic and atmospheric feedbacks, resulting in a SST anomaly spectrum that should be white at periods longer than a few years. Away from the western boundary currents, stochastic wind stress curl forcing causes primarily baroclinic fluctuations in the ocean interior, hence SST changes by mixed layer modulation. In quiet regions, the variance of the geostrophic pressure fluctuations increases with the distance from the eastern boundary and their dominant time scale is set by Rossby wave propagation. The spectrum is red but flattens at periods longer than 10 to 20 years, because of fetch limitation. In some coupled GCMs, the decadal variability is enhanced by an active air-sea coupling, while in others the ocean appears to be primarily passive.

ATMOSPHERIC CIRCULATION RELATED TO OSCILLATIONS IN SEA-ICE AND SALINITY (ACROSS) - A SPECIAL STUDY OF THE IMPACT OF BALTIC SURFACE RUNOFF ON ARCTIC SEA-ICE EXTENT

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The objective of the ACROSS project is to understand observed quasi-periodic oscillations in the ocean-atmosphere system over the past century, as well as longer term variations in the climate of the Nordic countries. The project has an underlying conceptual model of how atmospheric circulation is related to persistent anomalies of sea surface salinity and sea-ice extent. Through couplings with sea surface temperature, it is hypothesised that the atmospheric feedback help to sustain a quasi-periodic oscillation, which has a long record of observational evidence, but so far no satisfactory explanation.
Through a separate study of the fresh water flux from the Baltic Sea it is investigated how sensitive the oceanic circulation in the Nordic Seas is to perturbations in the boundary conditions. The large extent of Polar sea-ice around Iceland during the Little Ice-Age may by this means be understood as a result of anthropogenic impact on the forest cover in North-western Europe.
Preliminary results will be presented from case studies of decadal changes this century, focusing on the NH warming of the 1920-30'ies, the Great Salinity Anomaly in the 1960-70'ies and the recent episode of nine consecutive mild winters in Northern Europe.

LONG-TERM VARIABILITY IN THE NORTH ATLANTIC OSCILLATION: SST GRADIENTS AND INTENSITIES OF SYNOPTIC PROCESSES IN THE MID LATITUDES

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The North Atlantic Oscillation (NAO) is associated with temperature differences between Greenland and Northern Europe, driven by the North Atlantic meridional SLP gradient which is reasonably linked to the synoptic activity in the North-East Atlantic mid latitudes. We consider the long-term variations of the intensity of short-period processes which account for various scales of synoptic and sub-synoptic variability. Statistical and spectral characteristics of synoptic transients are obtained from different data sources (ECMWF and NCEP Reanalyses, VOS, long-term observations at OWS). They indicate interannual and decadal variations consistent with the variability of the NAO index. Midlatitudinal SST gradients are considered to be an agent driving changes in the synoptic activity on interannual and interdecadal time scales. Particularly, early 1970s, known as a period of the rapid transition of NAO from the GA to the GB regime, indicate consistent changes in SST gradients and synoptic activity. Statistical evidence and physical mechanisms of this link are discussed.

ANALYSES OF TEMPERATURE AND PRECIPITATION SERIES FROM THE NORWEGIAN ARCTIC.

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Temperature and precipitation series from Norwegian Arctic areas have recently been tested for homogeneity using the standard normal homogeneity test. The present analyses of the homogenised series focus on spatial and temporal variability of seasonal and annual temperature means and precipitation sums from the 1920s to present. Low pass filters are used to describe the decadal variability. Comparisons are drawn to the results from similar analyses in the North Atlantic area. The temperature curve for the Norwegian Arctic areas shows largely the same periods of temperature increase and decrease as the similar curves for the North Atlantic and for the Northern Hemisphere. However, the temperature increase before the 1930s and the decrease from the 1940s to the 1960s were larger than further south. The present level of the annual temperature in the Norwegian Arctic is below the temperature optimum in the 1930s. The autumn and winter temperatures show similar features as the annual curve, with an optimum in the 1930s or the 1950s. The spring temperatures show a steady positive trend, while the level of the summer temperature shows little variation. The spacial distribution of precipitation is rather complex, and it is not convenient to present one curve which is «representative» for the Norwegian Arctic. Some areas have experienced an increase in the precipitation level, while the annual precipitation in other areas has varied about a constant level.

STATISTICAL-DYNAMICAL ANALYSIS OF MULTIPLE DECADEL LONG ATMOSPHERIC SIMULATIONS USING THE ECHAM3 MODEL UNDER GISST FORCING

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The changes of climate means between the decades with El-Niño and with La-Niña events have been examined. This is done by data from the ECHAM3 model under GISST forcing. The SST data of these periods are used to provide the boundary conditions for atmospheric climate simulations and are taken from the Global Ice and Sea Surface Temperature data set. This simlation data are used to study whether there are significant atmospheric flow differences between the two decades associated with the externally varying boundary conditions. This is examined by means of describing selected climate parameters (surface pressure, stream-function and velocity potential). These parameters are integrated into a phase state vector $\vec{x}$.
The analysis (Hotelling T^2 and a variant of linear discrimant analysis for monthly means) is done in the subspace of amplitudes of suitably defined three dimensional modes derived from simplified models.

TYPICAL SYNOPTIC PATTERNS IN THE GREATER MEDITERRANEAN REGION: INTERANNUAL TO DECADAL VARIATIONS.

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H. F. Diaz (CDC. NOAA, Boulder, Colorado)
P. Ribera Rodríguez (U. Complutense de Madrid)

The characteristic synoptic patterns controlling the behavior of temperature (T) and precipitation (R) over the Mediterranean region are investigated. The overall geographic area considered is 80N-20N latitude, 40W-50E longitude. Monthly values of T and R are considered for a period of 50 years, with a total 130 and 264 stations for T and R, respectively. Seasonal rotated principal components analysis (RPCA) has been performed for both series and typical composites for surface pressure (SLP) and 500hPa geopotential heights (Z_{500}) have been calculated. Interannual to decadal variations of seasonal SLP and Z_{500} are presented and discussed in the context of variations in T and R.

NUMERICAL INVESTIGATIONS OF THE VARIABILITY OF ARCTIC SEA ICE

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A dynamic–thermodynamic sea ice model with daily atmospheric surface forcing is used to investigate interannual variability of the Arctic ice cover. The model area covers the entire Arctic and the adjacent Greenland Sea with a horizontal resolution of 1°. A consistent, long-term atmospheric forcing data set is derived from the NCEP/NCAR Reanalysis Project for the period 1979 to 1995.
The interannual variability of the ice thickness distribution, which is poorly known from observations, is modelled. The interaction of the simulated ice drift with the ice-thickness buildup results in interannual variability of the ice volume transport through Fram Strait and hence in variations of the freshwater input into the North Atlantic Ocean. Correlations of atmospheric forcing fields with ice thickness distribution, ice drift and Fram Strait ice volume transport are calculated.

DECADAL VARIABILITY OF THE MAIN THERMOCLINE EXCITED BY STOCHASTIC WIND STRESS FORCING

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There is some evidence that modes of decadal time scale exist in the main thermocline. It was suggested that stochastic wind stress forcing might explain a substantial part of this variability. To investigate this further an isopycnic OGCM is used. The Model domain is the Pacific Ocean. The questions posed are: 1.Is it possible to generate large-scale variations in the model thermocline system solely by daily variations of the weather ? 2. Are spatially coherent patterns required in the forcing ? 3. What does the spectrum of the response look like ? 4. Which mechanisms are responsible for the evolution of the structures ? In order to answer these questions two experiments have been designed. For both, daily anomalies of wind stress are superimposed on the climatological wind stress forcing. In the first experiment, the daily wind stress anomalies reveal the spatial characteristics as derived from ECMWF analysis. In the second one the wind stress anomalies do not have any spatial coherence. The results suggest that large-scale variations can be exited on the decadal to centennial time scale, the patterns in the forcing play no role and that the spectrum is red down to the centennial time scale without any significant peak.

SINGULAR MODES AND INTERDECADAL VARIABILITY

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Observations and climate model experiments show that interdecadal oscillations of sea surface temperature (SST) anomalies are often accompanied by similar, spatially coherent variations of the atmospheric circulation. Thereby, the mechanisms that lead to such coupled modes of the ocean-atmosphere system are - at present - still under controversial discussion.
In the present paper we shall examine the possibility that the atmospheric components of these interdecadal modes are due to their interaction with the long-term climate mean atmospheric wave field and that one branch of this interaction is manifested in the excitation of internal, atmospheric modes, in particular, in the singular modes of some linearized, steady-state atmospheric model. This hypothesis is examined using a simple baroclinic quasi-geostrophic model, whereby data from climate model experiments are utilized to define the long-term mean basic state. Some preliminary results of these investigations will be presented. It is hoped that these experiments will provide some evidence on the mutual role of tropical and extratropical processes for the excitation of the coupled interdecadal modes.

STATISTICAL ANALYSIS OF THE INTERDECADAL VARIABILITY OVER THE NORTHERN HEMISPHERE

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The climate variability in the 10-50 year band over the Northern Hemisphere is described, using a 500-year integration of the Hamburg ECHAM1/LSG coupled general circulation model. In order to isolate nearly periodic components of the atmosphere and the ocean, the multichannel version of the singular spectrum analysis (M-SSA) is applied. One interdecadal oscillation of the coupled system ocean and atmosphere is detected with a period of about 18 years. It is found that the sea surface temperature (SST) anomaly is primarily generated by the heat fluxes and the temperature advection in the upper ocean layer. The strongest amplitudes of the geopotential height at 500 hPa anomaly are situated over the North Atlantic, North Pacific but also over North Russia, suggesting a more active role of atmosphere than of the ocean.

WARMING EVENTS IN THE ARCTIC OCEAN

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Recent high quality hydrographic measurements in the Arctic Ocean have revealed a warming of up to 1 K of the Atlantic layer when compared to Russian climatologies of the 1940s to 1970s. About half of this warming can be attributed to the different methods by which the two data sets were obtained: the climatologies are based on discrete bottle data in the vertical and necessarily involve smoothing in space and time, whereas modern quasi-synoptic data from continuously recording CTD sondes give much better resolution in the vertical. The remainder of the observed warming can be explained by an increased inflow of Atlantic Water in the early 1990s, and a higher temperature of this inflowing water. Temperature time series in the Barents Sea since the beginning of this century suggest that the warming of the 1990s is not a long-term climate signal, but related to the inherent natural variability of the system with time scales of 3 - 10 years. The time scales of progression of the warm patches in the Arctic basins are studied using a simple multi-layer numerical model. First results of these simulations will be discussed.

INFLUENCE OF VARIABLE SURFACE BUOYANCY CONDITIONS AT HIGH LATITUDES ON OCEAN CIRCULATION IN AN OCEAN AND ICE PRIMITIVE EQUATION MODEL OF THE NORTH ATLANTIC AND ARCTIC OCEANS

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The three-dimensional pathways of the Meridional Overturning Cell (MOC) in the northern North Atlantic are examined using the Princeton Ocean Model coupled to a dynamic and thermodynamic sea ice model. Dense water formation due to atmospheric buoyancy forcing occurs across progressively denser isopycnals both in the Subpolar Gyre and north of the Greenland-Scotland Ridge. An imposed shutdown of atmospherically forced dense water formation in the Subpolar Gyre of duration 5-10 years leads to a reduction in the strength of the MOC and in the meridional heat transport. However, the magnitude of the reduction is only 50% of the reduction in dense water formation rate. The gyre circulations exhibit relatively small changes on these time scales. Experiments with different (realistic) magnitudes of ice export from the Arctic through the Nordic Seas to the Subpolar Gyre lead to comparable changes in the MOC, decreased ice export leading to increased MOC strength and vice versa. By changing the buoyancy conditions through melting in the dense water formation regions of the Labraodor Sea, the sea ice can influence the MOC strength.

TRENDS, INTERDECADAL AND INTERANNUAL OSCILLATION IN NORTH ATLANTIC SST

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Multi and Monte Carlo Singular Spectrum analyses have been used to extract long-term trends and quasi-regular oscillations of global sea-surface temperature (SST) anomaly fields on global and regional scales. The strongest climatic signal is the irregular long-term trend. It seems that large-scale warming and cooling is preceded by similar behavior off the southern tip of Greenland (and soon thereafter over the Central North Pacific).The two major oscillations in North Atlantic, apart from this long-term trend, peak near 13-14 and 7-8 year. The 13-14 year oscillation exhibits a seesaw pattern between the Gulf Stream region and the North Atlantic drift, and affects also the Tropical Atlantic. The 7-8 year oscillation is very different, with anomalies of the same sign extending over most of the basin and reaching their strongest amplitude over the North-West part of the subtropical gyre. The dominant atmospheric pattern of North Atlantic (North Atlantic Oscillation) supports also a long-tern trend and a 7-8 year oscillation, when seasonal values of December-March are considered.

ON THE NATURE OF THERMOHALINE CHANGES AT INTERMEDIATE DEPTHS IN THE NORTHERN ATLANTIC.

Logoutov O.

A great deal of present-time researches are inclined to relate the long-term variability of oceanic properties at intemediate depths mostly with operating of thermohaline "conveyer". The main issue of presenting work is to argue for more diverse approach which may be rather expedient in that problem. Direct atmospheric forcing is considered as the factor of long-term variability at intemediate depths. A simple model of pycnocline's response on the changes in basin-wide wind fields is studied. Pycnocline is considered to be associated with thermo- or halocline depending upon the region. While designing the model we had a purpose to investigate the principal opportunity for variations of different time scales to penetrate at intermediate layer in definite regions by virtue of observing changes in basin-wide wind fields. The tendency of increase of atmospheric forcing influence upon the oceanic intemediate layer with an increase of temporal scales has become an imposing point of the results, so that we expect even small in amplitude decadal pertubations in wind stress fields (10**-3 n/m**2) be able to exert a definite influence upon the oceanic intemediate interior.

DECADAL CHANGES IN THE NORTH PACIFIC OCEAN: SUBDUCTION, ADVECTION AND WIND FORCING

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Observed decadal scale changes in the North Pacific upper-ocean (0-400m) temperature field will be discussed for the 1970-1994 time interval. A retrospective simulation will be used to diagnose physical processes of these observed thermal changes. In the central North Pacific, surface layer temperature changes are dominated by atmospheric heat flux forcing combined with vertical mixing and Ekman current advection, while deeper in the water column, anomalous subduction towards the equator appears to influence the temperature field. The magnitude of this subducted signal may be obscured by interannual propagating waves and direct isotherm displacement by atmospheric Ekman pumping. Near the western boundary, in the Kuroshio/Oyashio Extension, gyre-scale thermocline response to basin-scale Ekman pumping is clearly evident and geostrophic current advection appears to contribute to surface temperature changes. The relation of these observed changes to mechanisms implicit in the North Pacific Latif-Barnett model oscillation will be discussed.

AN ANALYSIS OF NORTH ATLANTIC SST ANOMALIES BY MEANS OF A LINEAR THERMODYNAMIC STOCHASTIC TWO-DIMENSIONAL MODEL

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The evolution of sea surface temperature anomalies (SSTA)in the North Atlantic is studied with a 2-D linear heat transport equation, with seasonally varying feedback and constant diffusion. A linear inverse procedure that gives an estimation of the value of these parameters as well as of the mean velocities from the covariences between observed SST anomalies has been developped. The procedure is tested in the analysis of different simulations generated by forcing a model of the same characteristics with different realizations of noise, white or red. The SST anomalies analized are from the period 1950-1992 and cover a domain from 20° N through 55° N. The values of the parameters and the estimation of the mean velocities are discussed and related with other statistical characteristics of the covariance field. Characteristics of the forcing noise are also investigated

VARIABILITY OF THE ATLANTIC INFLOW TO THE NORWEGIAN SEA

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This study deals with transport estimates of the Atlantic inflow to the Norwegian Sea based on long-term current measurements from April 1995 to October 1996 in the Svinøy section. This section just to the north of the Faroe-Shetland Channel cuts through the core of the inflow where different branches merges through confluence in the shelf break area, making this site very suitable for monitoring the inflow. The monitoring program is in progress and will continue into the next century. Our findings show that the Atlantic inflow occurs as a 30 km wide, nearly barotropic current trapped over the steepest slope between depths of 200 m and 900 m. Transport estimates based on a linear regression model show an along-isobatic inflow with strong variability between 0 Sv and more than 10 Sv. The fluctuations range from a few days to two months with a remarkable stable flow of 5-7 Sv on seasonal basis, in contrast to the commonly accepted annual cycle.

THE FSO AND THE NORTHERN HEMISPHERIC CLIMATE

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At latitudes higher than approximately 50°N, the sea level in the North Atlantic displays a distinct signal with a period around 14 months and largest amplitudes in the Norwegian, North and Baltic Seas. Previously, this signal has been interpreted as a dynamic pole tide induced by the Chandler Wobble. However, the temporal variations of this signal are not correlated with the variations of the Chandler Wobble. Moreover, in air pressure a similar signal can be found with the largest amplitudes of as much as 200 Pa over Northern Europe and Siberia. Within the last 100 years, the signal displays four (around 1902, 1919, 1955 and 1976) rapid (durations of the order of two to five years) transitions in period between intervals of remarkably stable periods. This temporal behaviour is coherently found in sea level and air pressure. The period jumps between 480 and 418 days, and the signal is therefore denoted as fourteen to sixteen months oscillation (FSO). The spatial and temporal pattern of this atmosphere-ocean phenomenon will be described in detail. The area of maximum amplitudes coincides with the region where a 65-70 year oscillation in temperature has been described in literature. Using the period jumps of the FSO to subdivide the hemispheric mean temperature results in segments with very small trends and means differing up to 0.4 K. Thus, the FSO may be related to rapid variations in the Northern Hemispheric temperature and climate.

MECHANICAL INTERACTION OF ATMOSPHERE AND OCEAN AT DECADAL TIME SCALES

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Climate variability at decadal to interdecadal time scales may, to a significant part, be associated with variations in the global atmospheric circulation pattern. Interannual to multidecadal sea-level variations at these time scales are partly resulting from mechanical forcing of the atmosphere, and, consequently, changes in the atmospheric circulation pattern are recorded in the sea level. Coastal relative sea level (RSL) acts as a low-pass filter of the forcing and, therefore, is particularly sensitive to variations of the forcing on longer time scales. The global data set of monthly mean sea-level data is used together with data sets of atmospheric parameters (in particular, air pressure) to study the decadal variability of coastal relative sea level in relation to atmospheric parameters over the last one hundred years. The derived global pattern in sea level indicates a globally coherent east-west fluctuation of typical durations between one and two decades with maximum coastal sea-level variations of 10 to 15 cm, which, due to the global nature of the signal, is likely to be forced by the atmosphere. In the North Atlantic, where data coverage is best, the signal appears to be in agreement with a slowly eastward travelling perturbation.

MANIFESTATIONS AND CAUSE OF THE DECADAL MODE OVER THE NORTH ATLANTIC OCEAN

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The goal of this talk is to study the North Atlantic manifestations of decadal variability of the coupled ocean-atmosphere system and its cause using historical data sets. Decadal mode is responsible for about 30 per cent of total variances of the annual sea surface/level temperature (SST/SLT), sea level pressure (SLP) and wind over the North Atlantic. It manifests as the coherent changes of the SST/SLT (mostly in the high-latitudes and West Africain upwelling region), SLP (mostly in the vicinity of Azor High and Iceland Low) and zonal wind (mostly over the North Tropical Atlantic). The decadal scale is due to the time of the baroclinic adjustment of the North Atlantic. However this is the coupled mode. The changes of the meridional heat flux over the North Tropical Atlantic due to changes of the Ekman transport in the Ocean is very important in its support.

VARIATION OF AIR TEMPERATURE OVER THE PERIOD OF INSTRUMENTAL OBSERVATIONS IN THE ARCTIC

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The present work is devoted to a detailed analysis of various aspects of variability in mean (T), maximum (TMAX) and minimum (TMIN) air temperature in the Arctic over the period of instrumental observations. Much attention has been paid to the search of the origin of spatial differences in variability of the analysed climatic elements. The Arctic is defined here after Atlas Arktiki (1985).

To reach the above mentioned goals two sorts of data were used: daily (10 stations, 1951-1990), and monthly, seasonal and yearly (35 Arctic and 10 Subarctic stations, for the entire observational periods). The daily data were needed to determine relations between air temperature and atmospheric circulation using synoptic climatological methods.

The analysis of yearly trends in T, TMAX and TMIN showed that, for the 40-70 years long series' which end in 1990, they are negative over almost the entire Arctic area. The seasonal data yield somewhat more complex pattern, nevertheless the negative trends clearly dominate. The autumn has cooled to the largest degree. The greatest disagreement of air temperature in the Arctic and in the northern hemisphere occurs since mid-70-ties.

Analysis of the trends in TMAX and TMIN showed that their behaviour is similar to that dominating on the entire Earth, i. e. they exhibit an asymmetric pattern leading to a decrease in diurnal range of air temperature.

THE INFLUENCE OF THE NORTH ATLANTIC SST ANOMALIES ON CLIMATE VARIABILITY OVER THE EUROPE AT INTERDECADAL TIME SCALE

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The influence of the North Atlantic SST anomalies on climate variability over the Europe is investigated. The outputs of the 700 year integration of the T21 version of the ECHAM3 atmospheric model coupled to the LSG ocean model has been analysed. The correlation maps between the SST index, defined as the average of SST anomaly (ASST) over the area 35°N - 55°N; 50°W - 10°W, and the sea level pressure anomaly, emphasise the tendency of the sea level pressure to be high over the regions with positive ASST. The structure of the 10 m wind and the 2 m temperature anomalies agrees with the distribution of the sea level pressure anomalies. The precipitation anomalies tend to be positive over the regions where the zonal wind anomalies are positive. The sea level pressure and precipitation anomalies extend eastward over the continent.

The leading atmospheric CCA mode is the North Atlantic Oscillation (NAO). The anomalies over the continent are related to the position and the intensity of the NAO. The power spectrum of the CCA1 time series emphasises two small peaks with a 15-20 year period which can be related to the North Atlantic mode, and a 40-50 year period which can be associated to the irregular oscillation of the North Atlantic termohaline circulation.

WINTER PRECIPITATION VARIABILITY OVER THE IBERIAN PENINSULA

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S. Nieto and A.H. Encinas (Dpto. E. y Matematica Aplicadas, Univ. de Salamanca, Spain)

M.D. Manso (Dpto. de Fisica, Univ. Aveiro, Portugal)

The interannual precipitation fluctuations have important consequences for agriculture in Spain. This paper examines the precipitation observations over the Iberian Peninsula for winter seasons during the period 1949-1995. To obtain the spatial and temporal patterns of precipitation variability we have used spectral, principal components and correlation analyses. Some interpretations of the variations are given by the relationships between precipitation and the dominant patterns of sea level pressure and North Atlantic Oscillation index. This paper will also focus on the long-range precipitation prediction by characterizing the time series with a combination of persistence, trend and significant oscillations.

NORTH ATLANTIC SEA-LEVEL VARIATIONS ON DECADAL TIME SCALES

P. Ruf and H.-P. Plag (Institut für Geophysik, Christian-Albrechts-Universität zu Kiel, Olshausenstr. 40, D-24118 Kiel, Germany)

Sea-level changes on decadal time scales are likely to be in part driven by atmospheric forces. Based on tide gauge data and air pressure data from the Permanent Service for Mean Sea Level (PSMSL) and the Carbon Dioxide Information Analysis Center (CDIAC), respectively, the relation of air-pressure variations and sea-level variations are investigated. Most of the time series of monthly means contain periods of missing data and they do not cover identical time intervals. To enhance the long-period signals, these time series are integrated over time after removing trends and seasonal cycles. The integrated time series are cross-correlated and geographical maps of the correlation coefficents and time lags are constructed for fixed selected coastal and island stations. On the basis of these maps, the geographical variations of the correlation of sea level and air pressure will be discussed.

TRENDS IN RADIATION REGIME OBSERVED IN ESTONIA

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The radiation budget of the earth's surface has an essential role to play in determining the weather processes in the atmosphere. Long-term changes in radiation budget (net radiation) and its components are examined together with changes in atmospheric transparency, cloudiness and air temperature. The investigation is based on the actinometric data obtained at Tõravere Actinometric Station of the Estonian Meteorological and Hydrological Institute (58.3°N, 26.5°E) during more than 40 years. Their analysis reveals significant decreasing trends in the time series of direct solar radiation, global radiation, reflected radiation, and atmospheric transparency. On the other hand, the annual values of net radiation, its long-wave component and low cloudiness have increased. As a possible cause for the observed increase in air temperature, the enchanced greenhouse effect is discussed.

The influence of pressure-patterns on temperatureanomalies for three time-series in Switzerland on a low frequency scale between 1785 and 1994

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The correlation-based classification of monthly sea-level-pressure-patterns over the eastern Northatlantic and Europe results in 12 classes. Although there are typical pressure patterns and combinations of them for each season, there is a big variability on a low frequency scale in the analysed period (1785-1994). Even the most frequent classes have variations in their occurance from one decade to another within a factor 2. The mean seasontemperatures are computed for the classes. Each class has typical temperatures, a large part of them are significantly different from the others. The seasonal analysis of the 210 years shows the changing influence of the atmospheric circulation on the temperatures for 3 Stations in Switzerland (Basel, Geneva, Grosser St. Bernhard). This circulation-induced temperature-variations, which are based on the seasonal means, are compared with the effectivly measured temperatureanomalies: there exists a significant correlation for winter and summer. It can be seen, that even rare classes with big temperature-anomalies have a stronger influence on the temperature-variability than more frequent classes with seasonal temperature means around the overall seasonal mean. Therefore it is possible to identify pressure patterns with big climaterelevance (for the temperatures) for the three stations. A variance-homogenity-test of the used dataset (NDP-025, Numeric Data Package 025 from the Carbon Dioxide Information Analysis Center) shows inhomogenities between the measured and reconstructed periodes in the Northatlantic and southern European sector.

NORTH ATLANTIC DECADAL VARIABILITY IN A CLIMATE MODEL OF MODERATE COMPLEXITY

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North Atlantic decadal variability is investigated with a climate model of moderate complexity, called ECBILT. The atmospheric part of ECBILT is a T21 global three level quasi-geostrophic model with simple parameterizations for the diabatic processes. It includes an estimation of the neglected ageostrophic terms. The oceanic model is based on the primitive equations.The horizontal resolution is 5.6 degrees. It has 12 layers and a flat bottom. A thermodynamic sea-ice model is included. Due to the moderate complexity of ECBILT many long integrations can be performed. ECBILT is integrated towards equilibrium without fluxcorrections. The simulated climate is compared with the observed climate. It appears that the simulated decadal (10-20 years) variability in the North Atlanticic corresponds qualitatively with the observed decadal variability. With a number of idealized experiments we have investigated the physical mechanisms and the dominant feedback-processes involved in this type of variability. Especially we have concentrated on the role of the coupling between ocean and atmosphere.

DECADAL VARIABILITY AND PREDICTABILITY IN THE NORTH ATLANTIC

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There has been much recent interest in trying to understand the nature and causes of decadal variability in sea surface temperatures (SST) in the North Atlantic Ocean. Some workers have suggested that much of this variability can be explained as a local ocean response to atmospheric variability, while others have argued that dynamical processes in the ocean play an important role. It is likely that both these mechanisms are important, though to differing degrees in different regions. An interesting possibility is that the decadal variations in SST arise as part of coupled ocean-atmosphere mode of variability. Recently, Grötzner et al. have proposed a mechanism for such a mode. As yet, however, their mechanism has not been subjected to detailed testing against observations. Nor has the potential predictability associated with the coupled mode been investigated in any detail.

We are using observational data sets to investigate the causes of decadal variability in North Atlantic SST's, to test the hypothesis of Grotzner et al. regarding the nature of a possible coupled mode, and to explore the potential predictability associated with such a mode. We have found encouraging evidence that decadal variations in North Atlantic SST may be more predictable than has been thought, and we have found support for some but not all aspects of the Grötzner et al. mechanism. We are now exploring the extent of decadal predictability in atmospheric variables and will report on these results.

INTERDECADAL VARIABILITY OF THE THERMOHALINE CIRCULATION UNDER FIXED-FLUX BOUNDARY CONDITIONS

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The Geophysical Fluid Dynamics Laboratory (GFDL) Ocean General Circulation Model is run under fixed-flux boundary conditions to determine if the interdecadal variability of the thermohaline circulation found in previous integration of the GFDL fully-coupled model is, or not, an ocean-only phenomenon. The fixed-flux boundary conditions for the temperature and salinity are given by the sum of the mean atmospheric fluxes, diagnosed from the previous coupled run, and the flux adjustment terms used in that coupled run.

Under fixed-flux boundary conditions, the thermohaline circulation shows no variability, even when a strong stochastic forcing (representative of the atmospheric "noise") is added. Contrary to what was usually thought, these results indicate that the interdecadal oscillation of the thermohaline circulation observed in the GFDL coupled model is not an ocean-only phenomenon that could occur under fixed-flux boundary conditions.

PACIFIC OCEAN RESPONSE TO DECADAL NORTH PACIFIC WIND STRESS ANOMALIES

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The decadal climate variability over the extra-tropical and tropical Pacific Ocean is investigated by conducting a series of numerical experiments. The analyses of data from multidecadal integrations of coupled ocean-atmosphere models and observations reveal a characteristic pattern of decadal sea surface temperature (SST) variations in the North Pacific with a dominant anomaly in the western and central North Pacific and anomalies of opposite sign to the east and south of it. This pattern was used as an anomalous lower boundary condition in an integration of the atmospheric general circulation model ECHAM3. The resulting pattern of anomalous wind stress was added over the North Pacific to the climatological forcing of a Pacific-only version of the "Hamburg Ocean Primitiv Equation"-Model (HOPE). We study the ocean adjustment to a suddenly imposed wind stress anomaly as well as to periodic decadal variations. The response is most dominant in the North Pacific, where the wind stress anomaly is applied, but changes can also be found in the Tropical and South Pacific, where no anomalous atmospheric forcing is imposed. The Pacific-SST response pattern resembles quite well the one that is associated with decadal climate variations. Our study shows the importance of extra-tropical decadal climate variability for long-term fluctuations in the Tropical Pacific. Finally, we investigate the impact of these fluctuations on the ENSO phenomenon.

DECADAL VARIABILITY AS A MODE OF THE OCEAN THERMOHALINE CIRCULATION

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Numerous simulations of planetary geostrophic ocean models have been carried out at coarse resolution to understand the conditions under which decadal oscillati ons are generated. They appear to be natural modes of thermocline variability un der a wide vari ety of flux boundary conditions. After a rather complete analysis of the oscilla tions observed with various turbulent closures for the momentum equations, the m ain features of the oscillations are extracted. Essentially advective, the mecha nism involves a coupling between the anomalies in the western boundary currents and temperature in the polar regions. The growth of oscillations is however controlled by a few model parameters such as the horizontal diffusivity. The role of Rossby waves o r boundary wave s seems to be excluded from the mechanism: f-plane simulations do reproduce the variability (Winton, 1996); northern and eastern boundaries are not necessary. Simplified models are then used to reproduce the essential proce! sses with few degrees of fre edom.

A NEW MECHANISM FOR GENERATING DECADAL VARIABILITY OF SEA ICE COVER IN THE GIN-SEA

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A coupled atmosphere-ocean-sea ice model is used to study interdecadal variability of sea ice in the Greenland-Iceland-Norwegian Sea. The model is driven by prescribed wind stress, annual distribution of solar radiation and temperature, salinity and ice fluxes on the open boundaries located at 60°N and 80°N. When ocean entraintment is taken to be inversely proportional to active layer depth the model spins up to regular annual cycle. However, when a physically more realistic entraintment law is used, unforced interdecadal pulses in winter ice cover occur. A negative feedback loop is proposed to explain this new mode of Greenland-Iceland-Norwegian Sea variability. The feedback loop consists of strong entraintment eastwards of the gyre centre which produces deepening of the active layer depth. This in turn (via Rossby wave propagation) causes an anomalous ocean circulation pattern which supports positive winter ice anomalies.

A further experiment demonstrates that the coupled atmospheric energy balance model significantly enhances the variability via the positive feedback between air temperatures and the influence on surface albedo of sea ice.

OA23 Climate variability: observations and modelling

04 Coupled atmosphere-ice-ocean model developments

Convener: Planton, S.
Co-Convener: Cubasch, U.

NORTH ATLANTIC OSCILLATION SIGNAL IN ATMOSPHERIC AND IN COUPLED ATMOSPHERIC/OCEAN MODEL RESULTS

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A number of studies have suggested that the North Atlantic Oscillation (NAO) is generated by the internal characteristics of atmospheric dynamics but the role of air-sea interaction in the NAO variability is still unclear. The study of the NAO phenomenon using model results could reveal the role of the ocean in the NAO development and persistence. The spatial and temporal features of the NAO signal have been found in the monthly sea level pressure (SLP) and surface air temperature fields obtained from the global atmospheric LMD 5.3 model, forced with the SSTs for the time interval 1979-1994. The spatial and temporal patterns of the NAO variability are identified using canonical correlation analysis. Similar features have been revealed in the SLP and surface air temperature fields obtained from the global atmospheric LMD 5.3 model coupled with the global oceanic OPA7 model. However, the NAO signal is stronger in the uncoupled model compaired to the coupled one. The presence of the NAO signal in the coupled model results makes possible further investigations of air-sea interactions related to the NAO predictive potential.

A COUPLED AIR-SEA-ICE REGIONAL MODEL FOR THE GREENLAND SEA

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The importance of the northern polar and sub polar regions on the Earth's climate system has been subject to much research throughout the years. In particular in climate research the importance has been addressed with much attention as these regions are sites for one of the Earth's major source for deep water formation, the Greenland Gyro region. The strong air-sea-ice interaction in this region is believed to play an important role in this process. To handle these physical processes realistically in a consistent way coupled air-sea-ice models are required.
With emphasis on the interaction between the atmosphere and the ice-ocean systems the significance of the feed-back mechanisms has been studied. The role of such feed-back mechanisms has been addressed using a standard atmosphere model and a coupled three dimensional ice-ocean model. The atmospheric model component is the HIRLAM model while the ocean-seaice component is the MIKE 3 model developed at the Danish Hydrolic Institute.
The model complex has been setup in both decoupled modes as well as in a coupled mode to form a fully coupled regional atmosphere-ocean- seaice model. As test case a two week period in 1994 has been selected and the model results have been compared to corresponding observations.

A COUPLED ATMOSPHERE–OCEAN GENERAL CIRCULATION MODEL FOR CLIMATE STUDIES

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A new coupled atmosphere–ocean model has been developed for climate predictions at the decade to century time scales. The atmospheric model is an improved version of the atmospheric general circulation model built at the *Laboratoire de Météorologie Dynamique* of the *CNRS* (Paris). Its horizontal resolution is 64 regularly spaced points in longitude and 50 points spaced in a sinusoidal regular distribution from pole to pole. Vertically there are eleven levels. The oceanic model is a free-surface, primitive-equation model that includes a detailed treatment of the vertical mixing and of the thermodynamic and dynamic sea-ice processes. The horizontal resolution of this global ocean model is $3° \times 3°$, and there are 20 levels along the vertical. The normal latitude–longitude singularity at the North Pole is overcome by using two grids, the second rotated grid covering the Atlantic from the equator to the Bering Strait. At this point, the throughflow is parameterized according to the geostrophic control theory. The coupling of the two models is achieved by means of a coupler. Here we discuss results of a 30-yr control run (without flux adjustment) conducted with the coupled model. A particular attention is paid to the model behaviour at high latitudes. Despite some systematic biases, the model robustness and stability are quite promising for future studies.

USE OF A NESTED SURFACE MODEL TO FORCE A HIGH RESOLUTION ICE SHEET MODEL FROM MEDIUM RESOLUTION GCM OUTPUT

Robin W. Glover, Paul J. Valdes and Isabelle Marsiat (Department of Meteorology, University of Reading, UK)

The disparity between the high resolutions required for reasonable modelling of ice-sheet dynamics and the typically much lower resolutions used for atmospheric GCM simulations lead to difficulties in coupling these types of model in a satisfactory manner. A surface balance model will be described which is forced by GCM output and generates a surface mass balance field on a finer grid suitable for coupling to an ice sheet model. Variability on scales smaller than that of the GCM grid is forced entirely by changes in surface altitude and the effects of this upon near surface atmospheric temperature, humidity and downward longwave radiation. The precipitation is also adjusted in line with the changes in near surface humidity, subject to overall conservation of precipitation amount.
The model produces a distribution of surface mass balance for Greenland that are qualitatively superior to those produced by the GCM alone, although the area averaged values are not substantially changed. Since the model is integrated off-line, it can be forced with archived GCM data from completed integrations, thus the entire process requires a minimum of computer resources. The sensitivity of a two-dimensional ice dynamics model to the change in effective resolution of the surface mass balance forcing will be examined.

IMPACT OF SEA ICE / ATMOSPHERE INTERFACE MODELING ON THE SEA ICE DISTRIBUTION IN GCMS

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In sea ice covered regions, the ocean surface is highly heterogeneous (open water, new ice, thick pack ice...). The sea ice GCM we developed takes this heterogeneity into account by allowing various sea ice classes, whereas atmospheric models used in coupled GCMs usually allow only homogeneus surfaces. We analyse how the sea ice distribution is modified by the following different sea ice / atmosphere interface models :
- the atmospheric model only considers one type of surface and fluxes over open water and over ice are similar
- the atmospheric model only considers one type of surface but the atmospheric heat flux is redistributed through an interface that approximates the spatial heterogeneity of the underlying surface
- the atmospheric model computes a separate flux over each of this type of surface

These results were obtained with the LODYC ocean/sea ice GCM coupled to a simple bulk atmosphere and with the full coupled IPSL GCM.

THE ARCTIC SEA ICE IN A GLOBAL ATMOSPHERE-SEA ICE-UPPER OCEAN COUPLED EXPERIMENT.

G.Garric (Dept. of Meteorology, University of Reading)

The polar regions act as the major heat sinks of the planet and are responsable for maintaining the thermal gradient between the equator and the poles which drives the general circulation of the atmosphere and ocean. Furthermore, the ice covered regions in the Arctic and Antarctic play a major role in the energy and water budgets of the planet. Climate simulations using general circulation models (GCMs) need to represent these regions adequately, especially if anthropogenic climate change is to be accurately predicted.
A coupled numerical simulation with an atmospheric general circulation model (AGCM), a thermodynamic-dynamic sea ice model and an upper ocean model is presented. An uncoupled sea-ice/ocean only experiment has also been performed and used as control reference to discuss the coupled run. The forced sea-ice/ocean simulation has not enough extent and volume of sea ice and generates a sea ice too compact. Furthermore, the polar regions are too warm and a possible reason for this is presented. A 5-year coupled experiment has more realistic polar temperatures, more ice volume and more extent. Coupling causes the sea-ice to be even more compact. The sea-ice production rates are examined in both the forced and coupled simulations and an attempt is made to understand the energy balance contributing to the ice production rate. In the central Arctic, the radiative fluxes play the major role in forming ice, whereas in the marginal zones, the oceanic heat flux is a significant contributor to ice destruction.

COMPARISON OF GCM-SIMULATED DAILY EXTREME TEMPERATURES WITH DATA OBSERVED IN THE CZECH REPUBLIC

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Studies dealing with the validity of coupled atmosphere-ice-ocean climate models have mostly examined annual, seasonal and monthly means of climate characteristics. In this contribution, time series of daily extreme temperatures produced by the GCMs are compared with the series of maximum and minimum temperatures recorded in the Czech Republic. Attention is focused on the annual cycles and autocorrelation functions, in particular on day-to-day changes as they are important in assessing impacts on agriculture. A few methods of seasonal cycle decomposition are examined. In estimating autocorrelation coefficients two different methods are used: standard procedures and the jackknife method. Differences between the GCM outputs and the observed datasets are tested.

SENSITIVITY OF AN OGCM TO THE RESOLUTION OF FORCING DATA

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In coupled atmosphere-ocean general circulation model experiments with about the same resolution for both models, most of the computing time is generally consumed by the atmosphere. The Hamburg atmosphere model ECHAM4 for example, requires about 21h CPU-time on a CRAY C90 for a one-year integration on a T42 grid, while the HOPE coupled ocean - sea ice general circulation model needs about 3h CPU-time when it is integrated on a T42 grid with a grid refinement at the equator which increases the number of grid-points by a factor of 3.6. With a T30 resolution, the ECHAM4 CPU-requirement is about 10h only. Using the T30 model version of ECHAM4 in coupled experiments instead of the T42 version thus implies a considerable gain in CPU time.
In order to investigate the sensitivity of the HOPE model to the horizontal resolution of ECHAM4, two integrations of HOPE in a stand-alone mode were performed, each of a length of 300 years. In both integrations the ocean model was forced with daily atmosphere model data which were obtained in a 15-year integration of ECHAM4 with climatological AMIP SST specified at the lower boundary.
A first analyses of the HOPE results indicates that the model performs comparably with both forcing data in low to mid latitudes.
Significant differences between the two integrations are found in the Southern Ocean and for the simulation of the ice cover in the Arctic Ocean.

TROPICAL CLIMATE VARIABILITY SIMULATED IN A COUPLED OCEAN-ATMOSPHERE GCM

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A multidecadal numerical experiment is realized by using the fully coupled ocean-atmosphere general circulation model developed at LMD and LODYC in Paris. Without any "flux adjustment", the coupled model can keep a reasonable mean climate state. The main objective of the present study is, however, to focus on the simulated climate variability, especially in the Tropics where the signal is strong and the results are more robust. Multi-channel singular spectrum analysis is used to describe the oscillations at different time scales: the semi-annual cycle, annual cycle and inter-annual cycle. Some physical mechanisms are proposed to explain the simulated tropical variability.

REORGANIZATION OF OCEANIC AND ATMOSPHERIC HEAT TRANSPORT IN AN OCEAN-ATMOSPHERE COUPLED MODEL.

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The evolution of the meridional heat transport is an important feedback in ocean-atmosphere coupled models. We will show in a simulation of the IPSL coupled model drifting towards a warm state that the reorganization of the heat transport yields to a meridional smoothing of the warming. During a first period, characterized by an enhanced heat greenhouse effect, the maximum heat uptake occurs in the mid and high latitudes. In this regions, the ocean heat tranport decreases. In the tropic, the pattern is more complex. The atmospheric heat tranport is more stable during this years. Then the reduction of the meridional gradient of the sea surface temperature yields to a reduction of the oceanic tranport at all latitudes, which is partly compensated by an increase of the latent heat transport in the atmosphere. We study how these changes affect the meridional repartition of energy, and then the global drift of the coupled model.
These results will also be contrasted with thoose of a second simulation, in which different parametrizations yield to a slightly too cold mean climate in the tropics, with nearly no drift.

THE ROLE OF SEA ICE REDISTRIBUTION IN SHAPING SEA ICE COVER FEATURES ON THE LARGE SCALE.

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A dynamic thermodynamic sea ice model was initiated in the framework of the "Ice State" European project at NERSC, and completed at CNRM. The model was primarily aimed at describing mesoscale processes, but applications on the large scale are now also investigated in the present study.
The main characteristics of the sea ice model that was used are the following : the number of sea ice types can be chosen, as well as the number of grid points when solving the vertical heat conduction equation in the ice and snow layers; an improved scheme for the evolution in time of snow physical characteristics was tested, and the thermal effect of brine pockets is modelled by a variable heat reservoir. Considering large scale sea ice dynamics allows to compute sea ice velocity divergence field, from which not only subgrid and large scale ice floe opening and closing are derived, but also kinematic sea ice redistribution. Simulations on the whole arctic basin were carried out in this framework and reproduced well observed average sea ice thicknesses and thickness distribution profiles.

Sensitivity of a global ocean–sea-ice model to inaccuracies in GCM-derived atmospheric forcing

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In the perspective of a climate change study, a global coupled large-scale ice–ocean model (CLIO) has been developed at the UCL. Its differents components are: the UCL free-surface ocean general circulation model and the UCL thermodynamic-dynamic sea-ice model. The horizontal resolution is 3°x3°, and there are 20 levels along the vertical. Prior to perform fully interactive atmosphere–sea-ice–ocean coupled experiments, we attempt to assess separately the adecuacy of two classes of atmospheric forcings derived from the AMIP extended run that has been performed with the version cycle 11-b of the Météo France ARPEGE AGCM to drive the ocean circulation and the sea-ice dynamics and thermodynamics: on one hand, the heat and fresh water fluxes, and, on the other hand, the momentum flux.
First, a 440 years control run is performed with the CLIO model driven by a climatological forcing. Then, two parallel integrations are pursued for 200 years. In the first one, the climatological heat and fresh water fluxes are replaced by those derived from the Arpège climatology. In the second experiment, the observed wind stress is replaced by those generated by the Arpège AGCM.
The results of the corresponding three experiments are compared, and the impact of changing the atmospheric forcing structure on ocean circulation and sea-ice distribution is determined.

SIMULATION OF STRATOCUMULUS WITH A STATISTICAL CLOUD SCHEME IN THE ARPEGE-CLIMAT AGCM

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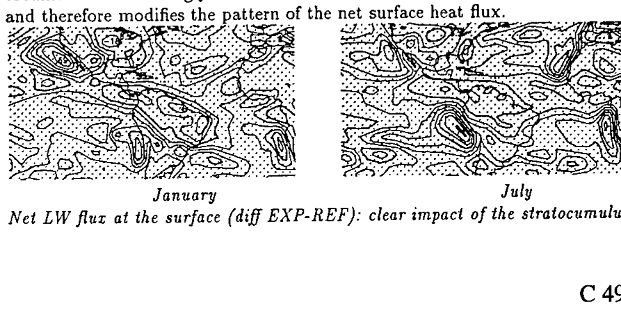
We analyse the results of two 14 month long simulations with the T42L41 Arpège-climat AGCM. These simulations are a preliminary step towards a coupled simulation with the OPA OGCM.
One simulation (EXP) has been performed with the Ricard and Royer (1993) statistical cloud scheme and is compared to a reference (REF) simulation. Thanks to an improved representation of the interactions between turbulence, radiation and condensation, stratocumulus cloud over the Eastern parts of the subtropical oceans is present in the EXP simulation. The presence of the stratocumulus cloud strongly decreases the solar and thermal fluxes at the surface and therefore modifies the pattern of the net surface heat flux.



Net LW flux at the surface (diff EXP-REF): clear impact of the stratocumulus

CLIMATE DRIFT ANALYSIS IN PACIFIC AND GLOBAL COUPLED OCEAN-ATMOSPHERE SIMULATIONS

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Major unresolved issues in coupled modelling involve model initialization, coupling strategy and climate drift. The latter does affect the climate mean state but also its variability. Furthermore, it is present in both global and limited domain coupled general circulation models (GCMs). If one wants to avoid the questionable use of flux correction, the understanding and reduction of climate drift are then one of the highest priority in climate research.

In this work, we adress the climate drift issue in two different ways: first we performed sensitivity experiments with a Pacific coupled GCM to the parameterizations of selected atmospheric processes such as convection and stratocumulus cloudiness. The simulated climate drifts are then analyzed in terms of zonal and meridional feedbacks of the tropical Pacific system. Second we show that meridional heat transport linked with energy and mass budgets can be used as tools to predict and analyze climate drift in global coupled simulations.

Long-term climate change to increased CO_2 concentration in a periodically synchronously coupled AOGCM

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The possible long-term climate change as a consequence to increasing CO_2 concentration is investigated in CO_2 doubling and CO_2 quadrupling experiments. The atmospheric CO_2 concentration of these two 700-year simulations follows the IPCC "Business as Usual" scenario A until CO_2 doubling or CO_2 quadrupling is reached and then remains constant for the following years. A 700-year integration with fixed present-day CO_2 concentration is used for comparison. The experiments were performed with the coupled atmosphere-ocean general circulation model ECHAM3/LSG. We applied the periodically synchronous coupling method where synchronous periods (the atmospheric and the oceanic models are integrated quasi-simultaneously) and ocean only integrations alternate. The reduced integration of the atmospheric model leads to a considerable reduction of the computer time compared to a synchronously coupled model (70% in the presented runs). In spite of the constant CO_2 concentration after 60 years in the $2xCO_2$ experiment and after 120 years in the $4xCO_2$ run the near surface air temperature increases further due to adjustment processes in the ocean. The warming also causes remarkable changes of the oceanic circulation.

NORTH ATLANTIC SPATIAL VARIABILITY OBSERVED AND SIMULATED BY 3 RUNS FROM THE HadCM2 CLIMATE MODEL

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Several authors have identified the NAO (North Atlantic Oscillation) as a major source of interannual variability in the northern Atlantic region. This important oscillation is significantly related to the interannual variability of Western European and North African precipitation (Hurrel, 1995). It is therefore necessary to assess the capacity of state-of-the-art GCM to model the NAO, and other modes of circulation variability in the North Atlantic region. We applied Principal Component Analysis to 30 years of SLP observations (1961-1990) and compared the results with a similar analysis performed on the same years in three different runs of a recent version of the Hadley Centre Model (HadCM2). These experiments are: a control run simulation (CC) with constant CO_2, a simulation with increasing concentrations of greenhouse gases (GG), and a simulation which includes forcing from both greenhouse gases and sulphate aerosols (GS).

The results obtained suggest the existence of a strong relationship between the first PC time series and NAO index for observations and the three simulations. In general the HadCM2 Model shows a good ability to reproduce the spatial patterns of the principal modes of circulation. Finally we performed a similar PC analysis on the three simulations but for a later period (2061-2090). The results obtained suggest, with few exceptions, that the spatial patterns and the explained variance of the principal modes of variability remain the same in the next century.

OA23 Climate variability: observations and modelling

05 Reconstruction of past climates through modelling and observations

Convener: Valdes, P.J.
Co-Convener: Ramstein, G.

UTILIZATION OF HISTORICAL CLIMATOLOGY FOR THE RECONSTRUCTION OF THE CLIMATE OF THE LAST MILLENNIUM: CASE STUDY FOR THE CZECH LANDS AND ITS EUROPEAN CONTEXT

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The role of historical climatology as a branch of science is defined in the study of past climates. Possibilities, advantages and drawbacks of man-made and natural data sources available for the reconstruction of the climate of the last millennium are characterized with a special consideration of utilizing written historical sources. The methodology of the quantification of written historical reports about the weather and related phenomena is presented. On the example of the Czech Lands the reconstruction of temperature and precipitation patterns and the occurrence of extreme hydrometeorological phenomena of the last millennium is made with a special consideration of the conditions of the 16th century. The found climatic fluctuations in the Czech Lands are presented in a broader European context. The suitability of the traditional concept of dividing the climate of the last millennium into the medieval warm epoch, the period of climatic deterioration, the Little Ice Age and the present warming with respect of the present knowledge of climatic fluctuation is discussed.

SENSITIVITY OF A GLACIAL OCEAN SIMULATION TO SOUTHERN OCEAN SURFACE SALINITY CHANGES

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δC^{13} measurements reveal large charges in the glacial ocean water mass properties. To explain the higher δC^{13} concentrations found in the North Pacific relatively to the Antarctic sources, deep subantarctic convection has been proposed to explain this reverse patern, compared to the present one. Taking benefit from new salinity data for the mid-latitude Southern Ocean, we attempt to address this question. Under LGM surface forcing (ECHAM wind stress anomalies, surface restoring to CLIMAP SST and *Duplessy et al.* (1991) SSS reconstruction for the Atlantic, +1 psu elsewhere), the UCL free surface OGCM is able to simulate a realistic glacial circulation. The main features of this control LGM experiment are a reduced NADW formation and a larger penetration of AABW, compared to present day, leading to a global cooling of $-3°C$. The sensitivity experiment is based on new salinity data (*Duplessy et al., in press*) from the Southern Indian Ocean: the zonal mean salinity anomaly has been zonally applied to the previous glacial forcing. The results show a very small impact on the global circulation and no deep convection is found in the subantarctic region. The major changes concern the AIW that become warmer and saltier than in the control LGM experiment.

CLIMATE AT THE LAST GLACIAL MAXIMUM: SENSITIVITY TO HORIZONTAL RESOLUTION

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The climate during the Last Glacial Maximum (LGM) has been simulated using the UGAMP GCM at different horizontal resolutions (T21, T42, and T63). The results suggest that both the global averaged climate changes and regional climate changes due to the imposed ice age boundary conditions are sensitive to the horizontal resolution. The regional climate changes simulated in a lower resolution model differ significantly from those in a higher resolution model due to the poor simulation in planetary waves and storm track activity. The results indicate that the lower resolution model cannot reproduce the present day climate as accurately as the high resolution model. Therefore, the simulated climate change using the lower resolution model is questionable. The results suggest that a T42 resolution is needed, at least for the UGAMP GCM, to simulate climate changes. This study implies that the model horizontal resolution is an important factor which should be borne in mind in exploring the model-model and model-data differences in the PMIP. Some of these differences may arise from the difference in the horizontal resolution.

IMPACT OF SEA LEVEL CHANGE ON CLIMATE DURING THE MIDDLE CRETACEOUS PERIOD

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The middle Cretaceous period is characterised by a warm and equable climate. Many forcing factors, such as paleogeographic distributions, high CO2 partial pressure, Equator-Pole oceanic heat transport, have been studied to explain this climate. Beside them, an important sea level change occured during this period producing extented epicontinental seas. Thus, to investigate the impact of sea level variations on climate and on large scale circulation, we have performed numerical experiments for two geological periods of middle Cretaceous, Aptian (120 Ma) and Cenomanian (94 Ma), respectively linked with low and high sea levels. Model outputs will be analyses with empasis on comparison with proxy data.

INTEREST OF TREE PHENOLOGY FOR PAST CLIMATES RECONSTRUCTIONS.

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Phenology received relatively little attention from ecologists and especially paleoecologists. Phenological data consisting on daily observations slowly accumulated are hard got; and experiments on trees phenology are difficult to achieve. However, because of their late sexual maturity and sometimes limited rate of dispersal, trees may be vulnerable to rapid climate changes. The relation between phenology and climate, especially temperature, is now well established. Some studies on the consequences of the expected Global Warming on tree phenology suggest that they may be sufficiently important to alter the competitive balance between species and consequently the forest dynamic. It is especially interesting to introduce phenology as explanatory variable of the forest dynamic in relation with the cyclic seasonal variations of insolation and temperature induced by the Earth precession. Our important aeropalynolgical dataset which concerns many taxa in different European localities of a transect (Abisko to Oran), permits the study of the relationship between tree phenology and climate at a macro-scale. Models of bud burst and flowering timing prevision have already been tested and applications to Global Change and Paleo-reconstructions of forest dynamic and climate are being to be develloped.

ICE CORE RECORDS OF CLIMATE VARIATIONS IN NORTHESTERN GREENLAND SINCE 1500 A.D.

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Three ice cores drilled in the so far little investigated northeastern sector of the Greenland ice sheet have been continously analyzed for their chemical (major ions) and isotopical ($\delta^{18}O$, δD) content as well as for their physical ice properties (AC/DC-conductivity, γ-density). This allowed, among others, the reconstruction of continous time series for isotope (proxy) temperature and snow accumulation rate in this cold (temperature $\sim$-30 °C) and very dry (snow accumulation $\sim$11 cm waterequivalent/a) area back to 1500 A.D. . The stable water isotopes in the two northernmost cores indicate a temperature decrease of approximately 0.5 °C during the 'Little Ice Age' but no recent temperature trend. Accumulation rate remained essentially constant throughout these two cores. The southernmost position, which is situated closest to Summit, however, shows only very subdued temperature variations, presumably due to the higher influence of cyclonic activity on the amount and isotopic signature of precipitation at this ice divide site.

RECONSTRUCTIONS OF PAST CLIMATE FROM HISTORICAL SOURCES IN CANARY ISLANDS

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The fluctuations of the climate in the course of the last millennium are usually divided into the warmer Medieval Warm Epoch between about 800-1300, and the colder Little Ice Age between about 1450-1890. This study analyses climatic fluctuations in Canary Islands from the middle of XV century to the end of XVIII century (the period when the Little Ice Age is present in other areas of the World). Canary Islands have two important singularities: 1) Their geographical position, close to the desert border, and 2) To have suffered volcanic eruptions during the period studied. Historical data are used to provide quantitative expressions of climatic data.

A SEMI-INVERSE OCEAN MODEL FOR THE INTERPOLATION OF SPARSE DATA

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To drive an atmospheric general circulation model, sea surface tempertures (SSTs) are needed as lower boundary conditions. These are well known for the modern ocean, but for other time slices the data base is very sparse and often complete global SST fields are not available. The necessity to provide SSTs as boundary conditions could be avoided by coupled modelling of ocean and atmosphere, but the coupling of sophisticated models is still connected with technical difficulties.

To circumvent these problems the "SIMPLE ocean" model has been developed, which estimates surface currents in a diagnostic manner from surface winds. Horizontal heat transports by advection and diffusion and surface heat fluxes are used to calculated SSTs. The unknown transports from the deep ocean are inversely estimated from sparse SST data. The model can be understood as a method to estimate a global SST field from a sparse data set, where it takes into account the wind driven surface currents.

In a preliminary control run for the modern ocean SST data from the core top samples of about 200 CLIMAP sedimentary cores are used. The resultant global annual mean SST field matches the observations with a root mean square error of 1.85°C. It is planed to couple the SIMPLE ocean model to the ECHAM atmospheric general circulation model, which would provide an effective tool for the simulation of important time slices of the late Quaternary.

SIGNAL ANALYSIS OF GLOBAL MEAN TEMPERATURE VARIATIONS SINCE 1866 BY MEANS OF AN ENERGY BALANCE MODEL

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We present an analytic solution of an energy-balance model which is calibrated with respect to satellite data, general-circulation model calculations and palaeoclimatic reconstructions. This analytic solution is converted to a recursive filter for time series analysis. Therefore we are able to analyse global mean temperature records without fitting any parameter to the time series of interest. The filter is applied to two natural and two anthropogenic forcing mechanisms which have to be expressed in terms of heating rate anomalies: volcanism, solar activity, greenhouse gases, and tropospheric sulfate aerosols. Thus we get modelled temperature variations and show that the observed (ENSO-corrected) global mean temperature time series can be explained by the considered external forcing and an additional white noise forcing. In this way we are able to separate different signals and compare them. As a result global anthropogenic climate change can be detected at a significance level of 99% without considering spatial patterns. The delay time with respect to anthropogenic forcing is calculated and a statistical-observational verification using a multiple regression model is carried out.

INTERCOMPARISONS OF SIMULATED AND OBSERVED VEGETATION DISTRIBUTIONS ACROSS EURASIA AND AFRICA AT 6000 yr B.P.

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The response of ten AGCMs, participating in PMIP, to the change in orbital forcing at 6000 yr B.P. has been investigated using an equilibrium biome model. The biome simulations show: reduction of tropical rain forest as a consequence of increased intertropical aridity, expansion of moisture-demanding vegetation and a shrinking of deserts as a result of the expansion of the Afro-Asian monsoons, an increase in warm grass/shrub in central Eurasia in response to mid-continental warming and aridity, and a northward shift in the tundra-forest boundary in response to a warmer growing season at high northern latitudes. Comparison with pollen-based biome reconstructions, made as part of the BIOME 6000 project, show the models consistantly underestimate the expansion of the Afro-Asian monsoon and the northward shift of the tundra-forest boundary, while generally overestimating the extent of mid-continental aridity.

OVERVIEW OF THE PMIP SIMULATIONS FOR THE MID-HOLOCENE CLIMATE

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The aim of the Paleoclimate Modeling Intercomparison Project, endorsed by both IGBP and WCRP, is to compare atmospheric general circulation models run with identical paleoclimatic boundary conditions (insolation,ice-sheet distribution and CO2 concentration). Two specific time-periods have been chosen for inital investigation: the mid-Holocene (6000 years before present) and the last glacial maximum (21 000 years BP).

All the models run under PMIP for the mid-Holocene climatic conditions exhibit similar changes, namely an amplification of the northern hemisphere seasonal contrast and of the summer Asian and African monsoon rains. Mechanisms are similar in all the models and follow the changes in the insolation forcing. However, the amplitude and the spatial structures of changes differ from one model to the other. Changes appear to be partly constrained by the present day simulated seasonal cycle as well as by feedback processes.

First comparisons with pollen and lake data, however, show that all the models understimate the amplitude of the northward extent of the African monsoon at 6 kyr BP which may be in part due to neglected feedbacks and/or inadequacies in the prescribed boundary conditions.

STORM-TRACKS AT THE LAST GLACIAL MAXIMUM: A PMIP COMPARISON.

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Extra-tropical weather systems are an essential feature of the mid-latitude climate and global circulation. At Last Glacial Maximum (LGM), the formation of regions of high transient activity, hereafter denominated 'storm-tracks', is strongly affected by the presence of large ice-sheets over northern America and Scandinavia and by differences in Sea Surface Temperatures (SST) distributions. In the framework of the Palaeoclimate Modelling Intercomparison Project (PMIP), simulations of the LGM climate have been run with a wide range of models using the same set of boundary conditions, prescribing the SSTs or computing them with a slab ocean model. This allows us to carry a valuable comparison between simulations of a climate very different from the present one. In our study, we focus on the storm-tracks representation in the models and their relationship with the surface temperatures, the mean-flow, and the precipitations. It is found that the general response to the changes in boundary conditions is consistent for all models, which nearly always give an eastward shift for both storm-tracks, with a larger shift for the Atlantic one. Differences reside in the value of the shift and the change in the storm-track amplitude, which we will analyse in terms of differences in resolution and parameterisations in the dynamics of the models, such as the diffusion parameterisation.

RESONANCE METHOD IN A RESEARCH OF GEOPHYSICAL PROCESSES

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Among principal problems of the analysis of time series it is necessary to note: detection of periodicity; restoration of missed observations on the basis of the being available information (construction of a model with allowance for of physics of the phenomenon); extrapolation (forecast) for a limits of an interval of observations. A new method of the spectral analysis possessing a surprising exactitude is offered. The method is free from defects inherent to classical methods, which developing during 200 years, (multiplicity of frequencies, false spectral lines, problem of computation of a true initial phase and amplitudes, problem of separation of neighboring periods etc.). In a basis of a method lays the phenomenon of a resonance. This method allows to investigate irregular one- and two-dimensional time series with a high level of noise. The method allows to reveal parameters of periodic processes (meteorology, geophysics, geodynamics etc.) with any beforehand given exactitude. The method allows to do the forecast a for want of limited amount and quality of the initial information about researched process. The method has shown the high effectiveness for decision of a problem of movement of Earth's instant pole of rotation (Chandler's movement), and also for research of dynamics of a variation of atmospheric pressure.

GCM's SIMULATION OF THE CASPIAN SEA LEVEL CHANGES DURING LAST 21000 YEARS

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A simplified GCM (MSU10x15L3) with an embedded limited area model (LAMBLS) was used to investigate the climate and hydrological regime sensitivity to the changes of the insolation flux at the top of the atmosphere, variation of the CO2 concentration and modification of the surface characteristics during the last 21 ka BP. It was shown that there were a lack of the explicit synchronization between global forcing factors and regional climate and hydrological changes. Hydrological anomalies over Caspian sea area and its catchment simulated by climate model are not sufficient to explain Caspian sea level changes during past 21 ka, espessially during Late Pleistocene ice age. To explain Caspian sea level changes during past 21 ka we must either implicate changes in some others nonclimatological factors (tectonically-induced variation of the basin configuuration, etc.) , or recognize that strong level variations occur due inherently to the nonlinear interactions in the system "large lake - catchment" which are influenced by the atmospheric forcing.

ONE MORE OUTLOOK ON LARGE GLACIAL MAXIMUM CLIMATE SIMULATED WITH ALTERNATIVE BOUNDARY CONDITIONS

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On the basis of analysis of the oxigen isotope composition of ground ice, pollen data etc., we have developed new scenario of the Last Glacial Maximum (LGM) permafrost field for Eurasia. Reliable data confirming that Eurasion permafrost LGM field expanded much more southward than nowadays gives us the real possibility to rearrange factors of ice age temperature decreasing at least over northern part of Eurasia. Obviously enormous fields of permafrost might be a significant feedbackmechanism supporting cold climate conditions. As a consequence we suggest ice sheets during LGM occupied noticeably less area unlike CLIMAP has being given us up to date. Both this new manner and CLIMAP information for LGM sea surface temperature were employed to simulate climate of LGM with the global circulation model of atmosphere of Moscow State University (MSU10x15L3). Results of modelling give obvious proofs that the presence of permafrost is followed by noticeable temperature decreasing.

ON THE REGULARIZATION OF THE INVERSE PROBLEM ABOUT THE PALEOCLIMATE RECONSTRUCTION

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The paleoclimate reconsrtuction problem consists in determining the earth surface temperature in the past. Moreover the distribution on the thermal parameters in the earth is supposed to be known. Such a problem is easily reduced to equivalent Fredholm integral equation from the first kind with help of the Green function of the parabolic differential equation with constant picewise coefficients. When solving the above problem there are mainly two difficulties: 1.Constructing an effective algorithm for calculating the Green function determining the kernel of the integral equation; 2. Getting to a stable solution of the integral equation of the first kind, representing a ill-posed problem. In the order to calculate the Green function we use its presentation to Fourier integral transformation with separating the subintegral function peculiarity. This enables us to work out fast algorithm for calculating the Green function. When solving the integral equation from first kind we use the Tikhonov's method of regularization in which the smoothing functional is ninimized. The algorithm offered is realized on a personal computer and allows for quick solving of inverse paleoclimate problem. The experiments carried out proved its high efficiency. This technique is applied in the paleoclimate reconstruction in Bulgaria and Russia.

LONG-TERM TEMPERATURE MONITORING ABOVE AND BELOW THE EARTH'S SURFACE

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A borehole 40 meters deep was drilled on the territory of the Geophysical Institute in the year 1993. Since then continuous measurements of temperature in 21 levels in the solid Earth as well as in two levels in the air has been performed. All measurements are accompanied with precipitation recording. A correlation between results from 2 meters and 0.05 meters above surface, surface and 0.05 and 0.1 meter depth was calculated. The rate of readings is 2 measurements in an hour at each level. The heat transfer between the air and soil depends on the quality of the surface layer, micro vegetation, thermal conductivity and diffusivity of the soil. As contribution of humidity may not be neglected, the precipitation recordings were taken in account too.
The objective of the study is to find out the nature of heat transfer from the air into the Earth in order to determine climatic changes in the past from temperature logging of boreholes.

CLIMATIC PROVINCES OF EUROPE DERIVED FROM LONG - TERM METEOROLOGICAL RECORDS

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The upper solid part of the Earth is touched by the air temperature that propagates into the depth with delay depending on thermal rocks properties. This knowledge discovers us the new path to decipher past climate changes. The great long temperature changes are preserved in the depth as departures of ideal temperature curves. To filtrate seriously these departures means to compare and calibrate the location of this anomaly in the depth with the real air temperature change in past.
As a very important background for both the studies of temperature depth records and the climate prediction is to study the past climate territorial development in order we may assess the relations between air temperatures and their reflections in the depth.
The statistic methods applied for the long - term records from meteorological stations of Europe enable us to divided this continent into several climatic provinces.
During the last two centuries, the characteristic courses that describe climate development typical for each of these considered provinces assign the own singularity in both wave-lengths and amplitudes. Despite general global warming , the each province carries its own significant features.

Preferred Atmospheric Moisture Sinks in the Antarctic, a comparison of recent climate and Paleosimulations

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The poleward atmospheric moisture flux as a qualitative indicator for the time dependent variations of snow accumulation in the Antarctic was investigated. Regions, characterized by time-mean atmospheric moisture sinks are identified. The interannual persistence of the inflow direction is also assessed . The investigations are carried out for the Holocene- and LGM-simulations of the (AGCM-)ECHAM3 and validated against the control-run and ECMWF-analyses.
The 10-year austral winter means of the vertically integrated moisture flux, which were derived from ECMWF-analyses, reveal three preferred inflow regions of moisture into Antarctica: Dronning-Maud-Land including the southern Weddell-Sea-Coast, Marie-Byrd-Land and a weaker one at Wilkes-Land. A close relationship to spatial patterns of the moisture fluxes at 60°S was found. In austral summer no preferred regions of inflow could be identified, except for a weak inflow pattern into Marie-Byrd-Land. The ECHAM3-control-run reproduces the results from the analyses but shows a decreased interannual variability. In the LGM-simulation the moisture fluxes show a much more meridionally orientated flow pattern when compared to the recent climate, but the total moisture fluxes are decreased. The same inflow regions are identified. The results for the Holocene-simulation reveal only small changes in comparison to the recent climate. However, an increase of the interannual variability of the inflow direction is observed.

SIMULATING LATE PLIOCENE NORTHERN HEMISPHERE GLACIATION WITH THE LLN 2-D MODEL

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Forcing the LLN 2-D model (Gallée et al., 1991; 1992) with insolation (Loutre and Berger, 1993) and an assumed linear atmospheric CO_2 scenario (Saltzman et al., 1993), we simulated the northern hemisphere ice-sheet volume variations from 2 to 3 Ma BP, and compared the simulation with geological records. In particular, the simulated glaciations over this million years correspond to the high dust fluxes off west Africa (Tiedemann et al., 1994); the simulated sudden glaciation around 2.75 Ma BP is coincident with the geologically observed major intensification of northern hemisphere glaciation at that time (Maslin et al., 1995). These comparisons suggest that the LLN 2-D model is able to simulate the approximate climatic characteristics of the late Pliocene, and the insolation variation might explain the suddenness of the major intensification of northern hemisphere glaciation around 2.75 Ma BP.

THE CLIMATE OF THE LAST GLACIAL-INTERGLACIAL CYCLE SIMULATED BY THE LLN 2-D GLOBAL CLIMATE MODEL

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The LLN two-dimensional climate model was extended to the southern hemisphere. It takes into account the main physical processes of the climate subsystems (atmosphere, ocean, sea ice, continents) and their interactions. An improved interactive hydrological cycle was included. Externally forced by the insolation and the atmospheric CO_2 concentration and asynchronously coupled to a model of the ice sheets and their underlying bedrocks this model has been able to reconstruct the low frequency of the climatic changes of the last glacial-interglacial cycle. Different sensitivity experiments are necesary to test the relative importance of different processes and to identify the mechanisms governing the climatic changes. Their global and hemispheric importance will be analysed. Results of these different sensitivity tests will be presented. Among them the insolation pattern, the atmospheric CO_2 concentration (considered as an external forcing), the vegetation change, the hydrological cycle are of particular interest.

STUDY OF THE SMALL ICE CAP INSTABILITY WITH A COUPLED ATMOSPHERE-SEA ICE-OCEAN-LAND ICE MODEL

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Energy balance models (EBMs) in which the snow and ice albedos are parameterized as step functions of the air temperature have multiple equilibrium states for a given value of insolation, Q. When the area of an ice cap is less than a critical value, Q_c, the ice cap becomes unstable. A slight increase in Q near Q_c leads to a sudden disappearance of the ice cap (Small Ice Cap Instability, or SICI). Decreasing Q from an initial ice free state leads to the reappearance of an ice cap for a value of Q below Q_c. The SICI relies on the albedo-temperature feedback whereby an increase (decrease) in air temperature leads to a decrease (increase) in the surface albedo via a decrease (increase) in the ice area, reinforcing the initial temperature perturbation. Here, we examine the existence of SICI events in a coupled atmosphere-sea ice-ocean-terrestrial ice model for the Southern Hemisphere. A two dimensional atmospheric EBM (AEBM), a thermodynamic sea ice model (TSIM), a uniform-depth ocean mixed layer model (OMLM), and a terrestrial ice sheet model (TISM) are coupled asynchronously. SICI events are studied for four different couplings: (1) AEBM alone; (2) AEBM-TSIM-OMLM; (3) AEBM-TISM; (4) fully coupled model. Cases (1) and (2) support SICI events, while cases (3) and (4) do not. This result casts doubts on the role of the SICI in the glaciation of Antarctic.

APPLICATION OF A PERIODICALLY-SYNCHRONOUSLY COUPLED AOGCM TO PALEOCLIMATIC TIME SCALES

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Global paleoclimatic boundary conditions at the atmosphere-ocean interface, which are generally not available, are made superfluous by the use of coupled atmosphere-ocean general circulation models (GCMs). Synchronously coupled GCMs have recently been developed for studying anthropogenic greenhouse warming. Typical simulation times are 200 years, which is sufficient for modelling small perturbations to the present climate. However, this is too short for simulating an equilibrium general circulation of atmosphere and ocean, which is the response of the model to the conditions at the remaining boundaries (land surface and distribution, insolation). Due to the long response time of the deep ocean one has to simulate at least 1,000 years.
In order to reduce the excessive computing time to run a synchronously coupled model a well-known coupled system (ECHAM-LSG, Cubasch et al. 1992) was expanded to the periodically-synchronous method (Voß 1996), i.e. short periods of synchonous coupling alternate with long ocean-only periods. Our application on paleoclimatic time scales is discussed. The control run is driven by "present interglacial" boundary conditions, i.e. modern land chracteristics, preindustrial CO_2 concentration and a mean insolation representing the last 1000 years. A series of experiments will be carried out in order to minimize the so-called flux adjustment. Presently, flux adjustments are used to avoid an artificial drift towards an unrealistic state of the global ocean circulation.

COLD PERIOD BEFORE RECENT GROUND SURFACE WARMING IN WESTERN CANADA - EVIDENCE FROM TEMPERATURE LOGS

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Analysis of 35 selected temperature well logs from Alberta, Saskatchewan, Northwest Territories and the Yukon in Western Canada shows evidence of extensive recent ground surface temperature (GST) warming in most cases exceeding surface air temperature warming interpreted from the time series for this century. The functional space inversion technique was applied to obtain GST histories. The temperature profiles were subject to a "loose" inversion procedure where part of the information is attenuated but which also ensures that the noise is not amplified. Two versions were considered, one with a priori conductivity and temperature standard deviations of 2 W/(mK) and 0.05 K, respectively, the other with 4 W/(mK) and 0.1 K. The combination (2 W/(mK), 0.05 K) represents lower uncertainty in an a priori information although the GST histories yielded by both versions do not differ much for individual wells. The a priori conductivity 1.6 W/(mK) is close to effective conductivity of the clastic rocks for the Alberta basin. In the majority of cases warming from the mid to late of this century is partially a recovery from a cold period with the minimum surface temperatures occurring sometime at the turn of the century. This result is compatible with evidence of a cold period with its minimum GST in the 19th century found from the temperature logs in wells of Quebec and Ontario, however western Canadian warming recovery came later in time than in the east.

PMIP model sensitivity to changes in the sea surface temperature.

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Model-data comparisons within PMIP are suggesting a number of regions where the models and data do not agree. The cause of any discrepancies may be due to model errors, but it could also be caused by uncertainties in the boundary conditions used by PMIP. Among a number of possibilities, past variations in sea surface temperature (SST) could be an important source of error. We present a number of sensitivity experiments using the UGAMP GCM to evaluate the possible magnitude of SST errors. The results suggest that uncertainties in SST are important but cannot explain all of the model-model and model-data disagreements.

REMOTE EFFECTS OF ATLANTIC MELTWATER INPUT SIMULATED WITH A COUPLED OAGCM

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The response of ocean and atmosphere to a prescribed input of meltwater into the North Atlantic has been simulated with the ECHAM3/LSG coupled ocean atmosphere general circulation model. Beside the expected effects of a collapse of the North Atlantic overturning cell and a strong cooling over the North Atlantic and Eurasia, the model also revealed significant climate changes in the tropical Atlantic and over the North Pacific. The combined effect of cooling and changes in the wind stress forcing lead to enhanced ventilation of the northeast Pacific at depths of a few hundred meters, in accordance with recent findings from sediment cores.

ON THE EFFECT OF PAST SEA LEVEL AND SALINITY CHANGES ON THE THERMOHALINE CIRCULATION OF THE MEDITERRANEAN

P. G. Myers and K. Haines (Department of Meteorology, University of Edinburgh, JCMB Kings Buildings, Mayfield Road, Edinburgh, U.K., EH9 3JZ)

During the last 18,000 years, the Mediterranean is thought to have gone through two extremes of climate: The Last Glacial Maximum (LGM) associated with increased salinities and decreased temperatures; and the Holocene Optimum (HOL) with low salinities and warmer temperatures. Sea level is also thought to have risen by about 120 m over the past 18,000 years.
A series of Ocean General Circulation Modelling experiments are carried out using a 1/4 by 1/4 version of the MOM-A model. The model is integrated with modified topography and coastlines consistent with the LGM and HOL periods to examine the influences of the changed bathymetry on the basin's thermohaline circulation. Further experiments include changes in the surface freshwater forcing to simulate salinity changes inferred from paleoclimatic data. The results are examined in the light of hypotheses on the formation of Sapropels in the Mediterranean during past times.

LAST GLACIAL MAXIMUM CLIMATE IN EUROPE AND MEDITERRANEAN BASIN : COMPARISON BETWEEN MODEL SIMULATIONS AND RECONSTRUCTIONS FROM POLLEN

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A new method to reconstruct past climate from pollen proxy-data has been applied to the Last Glacial Maximum in Europe. The method rests on notion of Plant Functional Type and biome concepts. The pollen taxa are converted into more broad classes according to their phenology and sensibility to climate. The reference dataset consists in new 1328 surface samples covering Europe; a set of 93 taxa is selected. The climatic variables are calibrated on these data using an Artificial Neural Network method : a non-linear method which avoid extrapolations beyond the modern climates limits. The method is applied to the glacial steppic vegetation in the Mediterranean basin and Europe, using data from the European Pollen Database. We reconstruct very cold January temperature anomalies (-20/-30°C) at north of the Pyreaneans-Alps line and less cold (-15/20°C) at the south. The gradient is in the same direction for the precipitation. In parallel, we compare our results with 12 LGM GCM simulations performed in the framework of the PMIP program. Both data and models show similar patterns with a enhanced cooling by 5 to 15°C in the models results (5 to 10°C warmer than the data). For the precipitation, the situation is more complex, but some models are able to reproduce the relatively wetter conditions of the South-eastern part of Europe.

DRIVING AN OCEAN MODEL WITH ATMOSPHERIC MODEL EQUILIBRIUM CLIMATES

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Traditional restoring boundary conditions for ocean models require the knowledge of sea surface temperature (SST) and sea surface salinity (SSS) distributions. For past climates, this knowledge is rather incomplete. Paleo SSS data is particularly sparse. A possible strategy for overcoming this lack of data is to drive an ocean general circulation model (OGCM) with surface heat and fresh water fluxes from atmospheric general circulation model (AGCM) equilibrium climates.
The modern and last glacial maximum (LGM) climates are studied. Two special problems shall be addressed: Firstly, the ever-present flux adjustments are to be minimized. Secondly, the effects of sea-ice are to be taken into account. The latter is necessary because at most the sea-ice extent but not its thickness can be reconstructed and furthermore AGCMs are usually run without an active sea-ice component.
The two ocean models employed are the Hamburg LSG and the GFDL MOM 2. For validating these ocean models against observations three tracers are used: SST, SSS and $\delta^{18}O$. The surface heat and fresh fluxes as well as the wind stress distribution are taken from experiments with the ECHAM 3/T42 AGCM. It is planned to extend this study to fluxes from other AGCMs which also participate in the Paleoclimate Model Intercomparison Project (PMIP).

MODEL/DATA COMPARISON FOR THE LAST GLACIAL MAXIMUM OVER TROPICAL AREAS.

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Simulations of the Last Glacial Maximum (LGM) climate have been run with Atmospheric General Circulation Model (AGCM) in the framework of the Paleoclimate Modelling Intercomparison Project (PMIP). These simulations used the same set of boundary conditions and for sea surface temperatures. two approaches have been developped: prescribed SST (CLIMAP,1981) or. computed SST. coupling the AGCM with a slab ocean. We shall focus our study on tropical area. analyse the response of the different models involved in PMIP and compare them to a new dataset using different paleoindicators. First results using only prescribed SSTs. show that the disagreement between data and models is now weaker than for previous comparison based upon snow line depression and the GISS model results (Rind and Peteet. 1985). Using the results of computed SST runs, most of models show colder temperatures than Climap dataset over tropical pacific, but the impact over terrestrial area remain very weak.

ICE SHEET MASS BALANCE DURING LAST GLACIAL MAXIMUM

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The aim of this study is to diagnose with two different approaches and models, the ice sheet mass balance at the LGM. In the framework of PMIP, several simulations of the LGM have been performed with the LMD AGCM and prescribed Sea Surface Temperatures (SST) (CLIMAP 1981) or computed SST (coupling a slab ocean to the AGCM). A first analysis consists in computing the water and snow budgets for the Laurentide and Fennoscandian ice sheets from the AGCM outputs. Results show a similar geographic pattern of snow accumulation over both ice sheets for versions using prescribed SST. The second approach uses the precipitation and surface temperatures results of the AGCM to force the LGGE ice sheet model and to investigate whether the initial ice sheet reconstruction (Peltier 1994) is in equilibrium with the LGM climate simulated by the AGCM. We show that the ice sheet model is very sensitive to the LGM climates simulated by the different versions of the LMD model, and that the higher resolution AGCM run, forcing the LGGE ice sheet model is able to maintain the Laurentide and Fennoscandian ice sheets.

A NEW LOOK ON CAUSE OF "LITTLE ICE AGE" AND GLACIATION PERIODS: COSMIC RAY FORSING

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The paleodata on the Earth temperature regime (T) and cosmic ray intensity (CR) for the last 150 kyr as well for the last 300 years are analysed. The analysis showed the synchronous temperature changes both in Northern and Southern Hemispheres as well at high, middle and equatorial latitudes. In the case the high correlation between T and CR intensity (concentration of 10Be) were discovered. The connection between T and 10Be can be presented by linear regression equation. Besides the experimental data on effects of CR on termodynamical property of the atmosphere were considered. It was shown that CR fluxes enhancement lead to temperature decrease in the troposphere. The numerical estimates of posible temperature decrease during "Little Ice Age" period on account of solar activity decrease and relevant CR fluxes increase give values equaled to about 0.6 degree C, that is very close to really observed values. On the basis of regression equation obtained between 10Be and T for the last 300 years the feasible temperature for 20-100 kyr B.P. are reconstructed. The temperature variations proved to be equal to (or some more) -(2-4) degree C, that had to led to ice age development. Thus between 20-100 kyr B.P. the cosmic ray forsing of climate changes took place. In the case the CR enhancement had been caused by sharp geomagnetic field decrease (up to 0.2 - 0.4 its modern value).

SEDIMENT TRANSPORT AND WATER MOTION DURING LAST GLACIAL MAXIMUM AND SUBSEQUENT MELTWATER EVENT

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Different numerical models are employed to simulate the global and the North Atlantic (NA) general circulation at two time slices – the Last Glacial Maximum (LGM) and a subsequent meltwater event (MWE) near 13,500 ^{14}C years B.P. to compare them with the present–day ocean circulation. A three–dimensional (3–D) sediment transport model and a semi–Lagrangian trajectory–tracing model were employed as add–ins to quantify sedimentation rates and pelagic sediment dynamics. The trajectory–tracing model is an especially useful tool to interpret ventilation of the ocean deep and to analyze changes of the routes of the major ocean currents. The numerical experiments indicate fundamentally different ventilation regimes in the NA which impose a remote control over the entire global conveyor. The sediment transport patterns show increased sedimentation rates in the eastern NA during both the LGM and MWE. The trajectory–tracing model visualizes the global conveyor and indicates a partly reversed global deep ocean conveyor during the MWE, clearly seen in the Atlantic and Indian oceans.

EFFECTS OF DEGLACIAL MELTWATER INPUT ON THE MODERN CIRCULATION IN ARCTIC OCEAN, NORDIC SEAS AND NORTH ATLANTIC. A MODEL EXPERIMENT.

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At the Last Glacial Maximum about 21.000 years before present large volumes of freshwater were stored in glaciers on the continents surrounding the North Atlantic, Nordic Seas and the Arctic Ocean. Melting of the ice sheets added substansial volumes of freshwater to the high latitude seas. In the modern clima te these areas are the major sites of renewal of the deep water in the world ocean as they probably also have been in the past. The response of the ocean circulation to the meltwater fluxes is believed to explain the highly variable climate during t he last deglaciation. On the basis of recent reconstructions of the paleo-topogra phy the meltwater rates into local discharge sites are derived. A simulation of the modern ocean circulation in the North Atlantic, Nordic Seas and the Arctic Ocean with a modified version of the Miami Isopycnal Ocean Model (MI COM) and a sea ice model is perturbated with the derived deglacial meltwater fluxes. The model utilize local orthogonal curvelinear grid with relatively high resolution focus on the Nordic Seas. The response of the modern circulation to the meltwater inp ut is discussed.

HOMOGENIZATION OF LONG EUROPEAN PRESSURE SERIES

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The homogenization of long mean monthly presuure series is being undertaken as part of the European Commission project ADVICE, Annual to Decadal Variability in Climate in Europe. Over 45 stations have been complied, updated, and homogenized. The data have been collected to cover Europe (including Iceland), the Near East and the Mediterranean region for the period 1780-1995. Homogenization techniques are based on difference series between individual stations and the United Kingdom Meteorological Office gridded data set (1880-1995), and on difference series between neighbouring stations (pre-1880). Some examples of homogenized series which have been produced for the ADVICE project will be shown, including those for Gibraltar and Stykkisholmur, from which an extended North Atalntic Oscillation series has been calculated (back to 1823). The homogenized pressure series will subsequently be used to produce a 5° latitude by 10° longitude grid. This grid will then be used to characterize circulation variability over the European region throughout the 215-year period.

SENSITIVITY OF THE SIMULATED MID-HOLOCENE AFRICAN MONSOON (6000 YEARS AGO) TO CHANGES IN SEA SURFACE TEMPERATURES

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Geomorphic and biostratigraphic evidence suggests that the summer African monsoon was much stronger and northwards expanded 6000 years ago than it is today. At the same time, summer insolation was 5% stronger over the northern hemisphere. A first attempt to explain the 6ka BP African summer rainfall increase has consisted in testing the monsoon sensitivity to this insolation change, using atmospheric general circulation models (AGCMs). Results of AGCMs simulations have shown that the 6000 yr BP insolation forcing was not sufficient enough to simulate the observed expansion of the African monsoon. Feedbacks from the surface may have amplified the orbitally induced increase in monsoons. Changes in the occurence of lakes, wetlands and vegetation into now-arid Sahara have been tested within AGCMs. Such changes act as a positive feedback on climate. For our part, we have tested the sensitivity of the mid-Holocene climate to regional change in sea surface temperatures, updated using data from marine sediments. We will present the results of our studies.

CAN CHANGES IN DRIFTWOOD DEPOSITION IN THE CANADIAN ARCTIC ARCHIPELAGO PROVIDE EVIDENCE FOR POSTGLACIAL VARIABILITY IN ARCTIC ATMOSPHERIC CIRCULATION?

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A.S. Dyke (Geological Survey of Canada, Ottawa, Canada)

It can be inferred from driftwood data collected in the Canadian Arctic Archipelago that very different sea-ice drift patterns were present in the Arctic Ocean during the Holocene. In this study, a recently developed sea-ice model, based on a granular material rheology, is used to examine the different modes of Arctic sea-ice circulation during this period, and also to infer characteristics of century-to-millenial scale changes in Arctic atmospheric circulation. The model is forced with prescribed ocean currents, air temperatures and with 1968 (strong negative NAO index) and 1984 (strong positive NAO index) winds, two years with drastically different winter climatologies, to assess how sensitive the ice-drift pattern is to the atmospheric forcing. The simulation results show that both a weak Beaufort Gyre with a broad Transpolar Drift Stream (NAO index < 0), and a wide Beaufort Gyre with a narrow Transpolar Drift Stream (NAO index > 0) can be reproduced, which Dyke et al. inferred from a radiometric analysis of the driftwood data. Based on the simulation results, the driftwood record also suggests that for long periods (centuries to millenia) of the Holocene, the atmospheric circulation resembled that of a negative or positive NAO index and abruptly changed from one state to the other.

MoBidiC, a two-dimensional coupled climate model to study abrupt climatic events

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MoBidiC model is new version of the Louvain-la-Neuve two-dimensional global climate model. It includes a coupling of a quasi-geostrophic atmospheric model with a zonally averaged, three basin ocean-sea ice model. It also contains an interactive representation of the hydrological cycle. This new model enables in particular to study the physical mechanisms linking the hydrological cycle, the ocean circulation and the climate. After a general description of the model, a control run under present-day boundary conditions and a series of sensitivity experiments will be presented. The perspectives to study abrupt climatic events with this tool will also be discussed.

PMIP Model Comparisons of the Changes in Planetary Waves at 6000 years ago and 21,000 years ago.

P.J. Valdes and B. Dong (Department of Meteorology, University of Reading, Earley Gate, Whiteknights, Reading. UK)

It is important to understand the changes in the mean atmospheric circulation for 6000 years ago and 21,000 years ago. We analyse the results from a number of PMIP model simulations. The results for 6000 years ago show a large amount of model-model variability. A number of specific characteristics can be identified, especially related to resolution of the model and its ability to simulate the correct present day planetary waves.

For the Last Glacial Maximum simulations, the changes in planetary waves are considerably larger than for 6000 years ago. However, there is still substantial model-model variability and this can be associated with changes in the surface temperature and precipitation fields. Unlike earlier model studies, most PMIP simulations do not exhibit large splitting of the westerlies around the Laurentide ice sheet.

A Climate Model Intercomparison for the Carboniferous

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T.J Crowley (Department of Oceanography, Texas A & M University, College Station, Texas, 77843 USA)

In an attempt to quantify errors associated with the basic formulation of palaeoclimate General Circulation models (GCM) experiments, we have compared simulations of the Carboniferous period by the National Centre for Atmospheric Research (NCAR GENESIS) model and by the UK Universities Global Atmospheric Modelling Programme (UGAMP) model. Results suggest that there are substantial differences in simulated temperatures and precipitation between the two models, even when using the same boundary conditions. The largest differences occur at the southern pole in summer, but there are also large differences in winter middle latitudes. It is tentatively suggested that the middle latitude differences are associated with the poorer horizontal resolution of the NCAR GENESIS model, whereas the high latitude differences appear to be resolution independent. Both models fail to simulate the temperate Gondwanaland climate proposed by the geological data.

SIMULATIONS OF HOLOCENE OPTIMUM CLIMATE

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We have employed the atmospheric general circulation model of the Canadian Climate Centre for Modelling and Analysis (CCCMA) to perform a series of simulations of the climate state that obtained near the Holocene Optimum at 6 kyr before present. The results constitute a contribution to the ongoing Paleoclimate Model Intercomparison Project (PMIP) and among the sequence of time slices that have been selected for analysis in this context the mid-Holocene period is certainly the least complex since by that time the continental distribution of land ice had returned essentially to its present interglacial form and sea surface temperatures may also have been close to modern. Our analyses focus on a number statistically significant signatures of the near Holocene Optimum state which are forced by the radiation regime determined by the orbital configuration that obtained then. Among these we will especially emphasize the response in sea ice cover in the polar regions and the response of the monsoon circulations of Africa, India and Asia. Comparisons have been performed with both fixed sea surface temperatures and with SST's computed using a version of the model that includes a mixed layer representation of the oceans. We will discuss a number of interesting characteristics of the magnitude and form of the response to this variation in the analysis procedure.

LAST GLACIAL MAXIMUM SIMULATIONS OF THE GLOBAL OCEAN

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D.P. Stevens and J.A. Johnson (School of Mathematics, University of East Anglia, Norwich, NR4 7TJ, U.K.)

A prescribed Last Glacial Maximum (LGM) atmosphere was used to force a global 3-dimensional ocean general circulation model. After 1000 years of integration the thermohaline circulation had deep water formation in the North Atlantic, but not in the Pacific or Southern oceans. The convective mixing in the model was then turned off in the North Atlantic for a further 1000 years. The North Atlantic overturning ceased, but after ~500 years overturning started in the Southern Ocean. The convective mixing in the North Atlantic was then turned on again at year 2000, but the state with only Southern Ocean overturning remained for a further 1000 years of integration. It is therefore suggested that there are at least two LGM states consistent with the LGM atmosphere used to force the ocean model.

BOUNDARY CONDITIONS FOR OCEAN FORCING FROM PMIP SIMULATIONS

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The Paleoclimate Modeling Intercomparison Project (PMIP) investigates the physical mechanisms of climate change and the sensitivity of climate models to different parametrization schemes. 17 AGCMs are included in PMIP simulating the atmospheric circulation for today (control run), 6000 years BP (Climatic Optimum), and 21000 years BP (Last Glacial Maximum). The results of these model simulations can be used to prescribe boundary conditions to drive models of the other components of the paleoclimatic system, e.g. ocean models.
To run an ocean model, net surface heat flux (representing the ocean surface net radiation, latent and sensible heat fluxes), net surface fresh water flux (representing precipitation minus evaporation and run off from rivers), and wind stress are needed. In PMIP these boundary conditions are calculated and compared (the output of the control runs are also compared due to observation data) in order to determine why the results agree in some determine why the results agree in some aspects and differ in others. The surface climatologies will be used to define mean and extreme boundary conditions to reconstruct the present oceanic circulation and the glacial oceanic circulation.

LONG-TERM INTENSIFICATION OF EXTREMELY HEAVY RAINFALL INTENSITY IN RECENT 100 YEARS

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Purpose of this paper is to estimate long-term trend of the heaviest rainfall intensity over Japan by data analysis , focusing on interdecadal changes of the parameters of Gumbel model of probability distribution for annual maxima of daily precipitation. In order to avoid the ambiguity in values of the model parameters estimated from a single station data , the data at 12 stations which are beforehand standardized are compiled into a single sample to be treated. It is seen that the location parameter of Gumbel model for the first 50 year period is greater , with statistical significance confirmed by the Monte Carlo method , than that for the last 50 year period. This result is expressed in terms of the daily precipitation for return period of 50 years , and the daily precipitation at Tokyo should increase from 240 mm/day during the first period of 1896～1945 to 279 mm/day during the second period of 1946～1995.

OA24/ST16 Solar cycles and global climate variability

Convener: Cini-Castagnoli, G.
Co-Convener: Duplessy, J.-C.

A POSSIBLE MECHANISM FOR COUPLING THE 11-YEAR SOLAR CYCLE TO MIDDLE ATMOSPHERIC VARIABILITY.

N. F. Arnold and T.R. Robinson (Department of Physics and Astronomy, University of Leicester, UK.)

Observations of climate variability have long suggested a link with solar activity. Whilst perturbations in the direct heating of the middle atmosphere by ultraviolet radiation do not appear to be sufficient to account for the observations, transport processes may provide a suitable mechanism. In this paper a possible mechanism involving the action of planetary scale waves is investigated.

An extended version of the UK Met. Office Stratosphere Mesosphere model (ESM) was used to demonstrate that over seasonal time scales, significant changes can be made to the winter middle atmosphere temperature and wind fields due to the difference in planetary wave propagation between solar minimum and solar maximum conditions. Relatively long dynamical time scales within the winter polar vortex allow small, non-linear effects to amplify.

ROLE OF SOLAR EUV AND SOFT X-RAY RADIATION PATROL FOR GLOBAL CLIMATE VARIABILITY INVESTIGATIONS

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The variations of solar activity influence on the weather and climate as well as on many other terrestrial phenomena and processes. The principal geoeffective part of the solar spectrum can be exactly EUV and soft X-ray fluxes, because the variations of all types: cyclic, with solar rotation, and the most intensive - during large solar flares, in these spectral ranges have the highest amplitudes. Therefore the permanent monitoring of solar EUV spectral radiation (of wavelengths less than 120 nm) for sufficiently long periods to fully assess the long-term variations is very important for global change research programme. At present in the world such a patrol does not exist but there is a plan of its realization by development of the Project "Creation of the permanent Space Patrol of Solar extreme ultraviolet and X-ray radiations". This Project was supported by the grant of Intern Science and Technology Center in 1996. The initial stage of this Project was financed by European Union with the scientific collaborators from France and Germany. In this paper the possible transfer mechanism of the upper atmosphere response on the solar activity to the ground is discussed. This mechanism is associated with the sporadic ionospheric radioemission of Rydberg states. The connection of the future Solar Patrol data with this problem is considered.

RECONSTRUCTION OF THE GEOMAGNETIC FIELD INTENSITY USING COSMOGENIC ISOTOPES

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Cosmogenic isotopes such as ^{10}Be, ^{36}Cl and ^{14}C are produced by the interaction of cosmic ray particles with the atmosphere. The galactic cosmic ray flux is modulated by the solar activity and the intensity of the geomagnetic dipole field. The solar activity is known to vary on different time scales ranging from hours to centuries and possibly also millennia. Changes of the geomagnetic dipole field seem to occur rather on time scales of centuries and millennia. Using paleomagnetic intensity records from sediment cores and a new relationship between production rate and field intensity the expected variations of the production rates of ^{10}Be, ^{36}Cl and ^{14}C have been calculated. They are compared to measured ^{10}Be and ^{36}Cl profiles in ice cores and the $\delta^{14}C$ records in tree rings and corals.

IS THERE A SUN INFLUENCE ON THE EARTH SURFACE TEMPERATURE VARIATIONS AT THE SECULAR TIME SCALE ?

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Numerical experiments have been carried out with a two-dimensional zonally aver aged global climate model in order to assess the potential impact of solar variability on the Earth's surface temperature over the last three centuries. This was done by investigating the model response to the variations in solar radiation caused by the changes in the earth's orbital elements, as well as by the changes intrinsic to the Sun.

Our results indicate that while the influence of the orbital forcing on the annu al and global mean surface temperature is negligible at the century time scale, the model shows an asymmetric hemispheric response to this forcing. The modeled global warming due to three inferred total solar irradiance reconstructions (Willson and Hudson, 1988; Hoyt and Schatten, 1993; and Lean et al., 1995) is insufficient to reproduce the observed 20th century warming. Nevertheless, the comparison between the simulated and the observed temperature variations suggest that prior to around 1970, the solar constant changes could have been a key climate forcing by introducing a large quasi-cyclic temperature variation of around 90 years associ ated with the Gleissberg cycle.

SOLAR CYCLES AND DOMINANT WINDS FROM TREE RINGS IN ARCTIC REGIONS

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The eccentricity of conifera trunk pith of the arctic McKenzie Delta, not reached by forest fires, can be taken as an indicator of dominant wind direction and the tree ring width in the same direction as a measure of their intensity. We have initiated such an analysis to find annual variability and first results will be presented; a possible relationship with solar cycles will be discussed.

THE 11-YEAR SOLAR CYCLE RECORDED IN THE THERMOLUMINESCENCE PROFILE OF SEA SEDIMENTS

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We have measured the thermoluminescence (TL) profile of the GT89/3 shallow water core of the Ionian sea (Gallipoli Terrace of the Gulf of Taranto). This core was previously dated by us with high accuracy. The TL profile, spanning the last 2500 years, has been obtained with a time resolution of 3.096 years, corresponding to a sampling interval of 2 mm. The analysis of the TL time series, performed with different methods, shows the existence of periodicities at both decennial and centennial (see peceeding abstract of this session) time scales. We discuss the affinity of these waves to the known cycles of the solar variability. This new profile:

a) confirms our previous analysis of the TL time series obtained by us in a different core GT14, taken in the same area, spanning the last 1800 years and sampled with a different time resolution of 3.87 years;
b) extends the previous record by 700 years;
c) confirms that the solar variability is imprinted in the TL profile of the sea sediments.

THE 11-YEAR AND THE CENTURY SCALE SOLAR VARIABILITY RECORDED IN COSMOGENIC RADIOISOTOPES IN METEORITES: INFERENCES ON THE SOLAR-TERRESTRIAL RELATIONSHIPS

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Production of cosmogenic radioisotopes depends on the galactic cosmic ray (GCR) flux, which is controlled by solar activity. The radioisotopes with suitable mean life can, therefore, serve as a proxy record of the behaviour of the heliosphere in the past, over different time scales. We have analyzed the available data of the activity ratio ^{22}Na ($T_{1/2}$=2.6 yr) to the long-lived cosmogenic ^{26}Al of about 30 chondrites which fell during the past three solar cycles. The results show a clear trend anticorrelated with the 11-yr solar cycle and increases by ~20% from solar maxima to solar minima as expected by model calculations. We have measured the ^{44}Ti ($T_{1/2}$=66.6 yr) in 11 chondrites which fell in the time interval 1840-1996. The phase of the trend of ^{44}Ti, corrected for Fe+Ni target element abundances, agrees with the calculated one, but the magnitude of the increase is 4 times higher than expected from modulation deduced solely by sunspot number. This different behaviour of the heliosphere during prolonged solar quiet periods such as at the turn of this and of the past century is discussed in connection to climatic variations.

CENTURY SCALE PERIODICITIES OF THE THERMOLUMINESCENCE TIME SERIES IN SEA SEDIMENTS: RELATION TO SOLAR VARIABILITY AND CLIMATE

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The profile of thermoluminescence (TL), spanning the last 2500 years, has been measured in the Ionian sea shallow water core GT89/3, with a resolution of 3.096 years, corresponding to a sampling interval of 2mm.

This sediment was previously dated by us with high accuracy by radiometric and tephroanalysis methods and shows a constant sedimentation rate (within 1%), uniform for a large area of this continental platform. The analysis of the TL time series shows clear periodicities at both decennial (see next abstract of this session) and centennial time scales. In particular, we have detected the periodicities of ~100 years, corresponding to the amplitude modulation of the sunspot number series, and of ~200 years, which is also present in the radiocarbon record in tree rings.

We discuss these results in connection with the solar-terrestrial relationships and the climatic variations in the last millennia.

O-AGCM simulations of the influence of variations of the solar constant on the global climate.

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Two simulations have been carried out with a global coupled ocean-atmosphere circulation model to study the potential impact of solar variability on climate using the Hoyt and Schatten estimate for the years 1700 to 1992. Results indicate that the near-surface temperature response is dominated by the long periodic solar fluctuations with global mean temperatures varying by about 0.5 K. The solar variability boosts the long periods which have so far been underestimated by a number of long simulations. The modelled temperature rise in response to the increase of the solar constant during the last century is not sufficient to explain the observed temperature rise. The solar variability induces a pattern of surface temperature change similar to the one caused by the increase of greenhouse gases, i. e. an increase of the land-sea contrast. Only during north - summer over sea regions significant differences between the response patterns of the solar variability and the greenhouse gas simulations can be found.

SOLAR SHAPING OF MEDIEVAL OPTIMUM AND LITTLE ICE AGE.

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It is pointed out that published periodicities found on the one hand in the time-series of central England temperature,on the other hand in the t-series of the bulk thermoluminescence profiles of recent Ionian sea cores,are certainly harmonics of a same 'fundamental' Solar forcing.In fact a multi-secular wave is well shaped from medieval optimum and little ice age,by the fitting of a low-order polynomial with decadal mud-thickness data of lake Saki.

EFFECT OF SOLAR INFLUENCE ON CLIMATE THROUGH QUASI BIENNIAL OSCILLATIONS OF SOLAR UV

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Even if solar irradiance doesn't vary significantly, variations in solar UV QBO (quasi biennial oscillations of UV) have influenced ozone concentration and stratospheric temperature. We find out that El Nino Southern Oscillation (ENSO) have periodicity that connected with periodicity of QBO. It's mean that the nature of ENSO may be connect with QBO. After about 11-12 years, atmospheric QBO connected with solar UVQBO will be found in identical phase with season-year periodicity and it express the effect of solar influence on climate. The mechanism of quasi biennial oscillations of ozone and of stratospheric dynamic in connection with UV QBO is discussed.

LONG-TERM VARIABILITY OF THE MESOPAUSE WIND FIELD AS SEEN FROM TOTAL REFLECTION WIND MEASUREMENTS AT COLLM, GERMANY

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The upper mesosphere and lower thermosphere wind field over Central Europe (52° N, 15°E) has been recorded automatically since 1973 by daily D1 LF wind measurements at the Collm Observatory of the University of Leipzig. These measurements are useful for investigating the mean mesopause wind climatology as well as the interannual variability of upper atmosphere wind parameters. Besides oscillations with periods of about 2-3 and 6 years and some solar cycle dependencies partly significant trends especially of the zonal prevailing wind and the semidiurnal tide have been found. However, a separate analysis of the first half (containing roughly the late 70s and early 80s) and the second half (the late 80s and the early 90s) of the time series show, that the obtained long-term trend is changing and, for some of the wind field parameters, even changes its sign. This gives some hint that an oscillation with a period of about two decades is present in the upper mesosphere that is overlaid to the overall trend.

SIGNIFICANCE OF SHORT-TERM INSTABILITY OF SOLAR IRRADIANCE IN THE SPECTRAL RANGE OF 330-520 nm

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Conditions and causes of short-term bursts ($t<90$ min) of solar radiation in the spectral range of 330-520 nm, discovered in the course of high-mountain observations of the spectral transparency of the atmosphere, are discussed. The bursts, defined as "gleams", occur in spectral regions centred mainly near the lines of the Balmer series. The half-width of a "gleam" band is no more than 20 nm, its amplitude exceeds by 20-40% the level of radiation typical for the quiet Sun in the same spectral range. It is found that the source of the gleams is an active region located near the central meridian of the Sun. It is suggested that the gleam irradiance has a nonequilibrium nature. It is doubtless clear that consideration of such "gleams" may be important from the viewpoint of climate change.

GLOBAL ATMOSPHERIC CIRCULATION RESPONSE TO SEASONAL AND 11-YEAR SOLAR CYCLES

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An attempt to relate the global atmospheric circulation of the Northern Hemisphere to the seasonal and 11-year cycles of solar irradience flux is presented. For that purpose a method is presented that aims to reduce the circulation to the time series of a single parameter. This parameter series depends on both the circulation and the external forcing time series. The correlation coefficient between the parameter series and the external forcing series depends on the forcing-circulation association. These procedures are executed for the external forcing series with different time shifts. The data of atmospheric circulation for 1899-1993 are presented by the calendar of the circulation patterns from the Dzerdzeevskii's classification. The external forcing is presented by the daytime duration series as a seasonal signal and the sunspot series as a 11-year cycle signal. On the basis of analysis it was found that the circulation is perturbed by the 11-year solar cycle with a confidence level of 0.95. Circulation response to the sunspot series is delayed for 7.5 or 18.5 years. The uncertainty in the time lag associates with periodicity of the sunspot series. Circulation response to the seasonal forcing is delayed for 17 days. As a result the phase-frequency characteristic of the Sun-circulation system is estimated in low-frequency, 11-year and 1-year bands by phase shifts and characteristic slopes equal to response lags.

FORECASTING THE GLOBAL CLIMATE VARIABILITY FOR THE 23 SOLAR CYCLE

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A new method of nonlinear spectral analysis was used to determine periodicities in annual mean sunspot numbers W for 1700-1993 yr. The calculated model set is discussed with a global climate variability. It is shown that non-stationary hyperlong harmonic of the model set with mean period of about T=252 yr. can explain common behaviour of the global climate. It is shown that a global climate will grow warmer for the future cycle. An unussually large value of W will occur during 23rd cycle (W will be greater than 100 during the 11-year period from 1997 to 2007)

SIMULATION OF COSMOGENIC NUCLIDE PRODUCTION IN THE EARTH'S ATMOSPHERE

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Calculations for the production of cosmogenic nuclides in the Earth's atmosphere are reported and discussed. We used a purely physical model that has been well tested with extraterrestrial materials for the calculation of cosmogenic-nuclide production rates in the Earth's atmosphere. The neutron spectra as a function of depth in the atmosphere were calculated by Monte Carlo simulations using LCS for interactions of cosmic ray particles with the Earth's atmosphere and the subsequent production and transport of secondary particles. Using calculated neutron and proton fluxes, the production rates of nuclides were calculated by integrating over energy the product of these fluxes and cross sections. We calculated production rates of ^{3}H, ^{7}Be, ^{10}Be, ^{14}C, and ^{36}Cl in the atmosphere by both galactic cosmic rays and solar protons. Calculations were carried out for various solar activities. Dependence of production rates on geomagnetic field was studied in detail, not only for the present field, but also for field intensities scaled by factors ranging from 0.05 to 2. Calculated production rates are compared with previous theoretical estimates and existing experimental data.

PLAUSIBLE SOLAR ACTIVITY IMPACT ON CLIMATE EVOLUTION IN CENTRAL EUROPE

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The near-Earth space is apparently forced by varying solar activity. A number of indicators of such forcing is broadly known, first of all response effects in the variable geomagnetic field. According to recent studies meteorological elements are likely to be among the possible indicators mentioned, too. The database available allows to address Sun-weather relations of immense complexity on a more systematic basis. To follow the plausible solar activity impact on climate evolution in Central Europe the data on air temperature and precipitation for more than 100 years on the territory of Slovakia are analyzed to assess and explain the longer term trends in time series profiles studied. Some features of climate changes are discussed from the viewpoint of solar and/or geomagnetic activity evolution.

LONG-TERM VARIABILITY OF THE SOLAR WIND DYNAMIC PRESSURE AND ITS CLIMATE CONSEQUENCES

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We studied long- term variability of the solar wind dynamic pressure for the satellite epoch - (1960-1993).There was a notable increase of this parameter since about 1972 and it still continues now while the solar spot number varies in its usual cyclic way. Comparing the rocket sounding data of the polar middle atmosphere temperature with the synchronous solar wind dynamic pressure values we found that the former parameter depends on the latter one,especially in winter and under the Eastern QBO orientation. We also found that the experimentally measured parameters of the ozone layer in the polar stratosphere depend on a position of the Earth magnetosphere magnetopause which is shifted toward the Earth with the solar wind dynamic pressure increase. We conclude that the solar wind dynamic pressure can influence the climate of the high-latitude regions during winter and under Eastern QBO orientation.

PHYSICAL REASON OF CONNECTION BETWEEN SOLAR CYCLE DURATION AND GLOBAL SURFACE TEMPERATURE.

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It is shown on some experimental data and model calculation that galactic cosmic rays (GCR) and episodically solar cosmic rays (SCR) can create additional aerosoles in the atmosphere. These aerosol clouds partly prevent from solar radiation input to the surface that leads in turn to some decrease of the ground temperatures. Taking into account the pronounced cyclic variations of GCR intensity it is demonstrated that the linear dependence between mean surface temperatures (Δ T) and solar activity (sunspot number W) takes place $\Delta T = 0{,}0051 W - 0{,}76$. On the base of physical mechanism suggested it is possible to interpret the well-known dependence of surface temperatures on solar cycle duration when during longer cycles the lower temperatures were observed and during shorter cycles the higher one. In the case the cycle durations turn not to be the causal factor influencing on global temperatures because experimental study on short and long time scales demonstrate that is a rule, the shorter cycles are as well the more intensive ones. So during the more intence periods of solar activity the aerosol layer is not developed enough on account of decreased activity of GCR. Some numerical estimates of global temperatures during last 300 years seem to support the physical model developed, on particular estimates of temperature conditions of Little Ice Age formation during Maunder minimum of solar activity corresponding to enhanced aerosol formation.

RESPONSE OF A SIMPLE COUPLED CLIMATE MODEL TO EARTH ORBITAL VARIATIONS: THE ROLE OF INTERNAL NONLINEARITIES AND STOCHASTIC RESONANCE

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Gerrit Lohmann (Max-Planck Institut für Meteorologie, Bundesstr.55, 20146 Hamburg, FRG)

A simple coupled model consisting of a northern hemisphere box ocean model and an energy balance model is used to study Late-Pleistocene climate variations. The astronomical theory of earth orbital variations is not able to explain the dominance of the 100-kyr peak in the climate record spectrum. We subject the question which role internal nonlinear climate feedbacks and stochastic pertubations (weather fluctuations) play to amplify the weak eccentricity forcing signal. The sensitivity of the model's thermohaline circulation on combined deterministic Milankovitch and stochastic weather forcing is studied. It occurs that the extreme stages of the past climate record are associated with multiple stable equlibria of the temperature-salinity driven ocean circulation.

SOLAR VARIABILITY AND COOLING OF THE UPPER ATMOSPHERE AS SEEN BY LONG-TERM MEASUREMENTS OF COSMIC RADIO NOISE.

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Model estimates of the effects of increasing greenhouse gas emissions predict cooling of the upper atmosphere. Experimental evidence for the cooling is, however, scarce and mostly based on short time scales. Since the absorption of cosmic radio noise depends on electron-neutral collision frequency, which in turn is a function of temperature, the cosmic radio noise measurements reflect long-term changes of temperature. We analyse the long-term recordings of the Finnish riometer chain for signs of cooling of the upper atmosphere and of solar variability. The Finnish riometer chain comprises 8 riometers, some of which started operation already in 1964; the chain covers the large latitudinal range between 60°31′ N and 69°45′ N.

LONGTERM VARIATIONS OF RADIATION BALANCE ELEMENTS IN THE EARTH'S ATMOSPHERE, AND COSMIC-RAY INTENSITY.

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An analysis is made of the radiation balance elements and atmospheric temperature at stations of the Baikal region in East Siberia. One of the geographical features of this region is that it lies in the central part of the continent where (according to various models) major changes in climatic characteristics as a consequence of global warming are expected to occur. A clear 11-year periodicity was detected in the scattered-radiation distribution for the period 1939-1986. Scattered-radiation maxima that are most pronounced in the spring-summer period, correspond to solar activity minima and galactic cosmic-ray intensity maxima. Some models treat cosmic rays as an "agent" that controls atmospheric transparency. The amplitude of scattered-radiation variations has been decreasing monotonically since the sixties. A decrease of maximum values of intensity is accompanied by an increase of maximum values, which is likely to be attributed to anthropogenic effects. It has been found that the increase in global surface air temperature during the past decade is manifested in the region being analyzed in the form of a rise in temperature in the winter months, while in the average the warming of the northern hemisphere is due to a rise in summertime temperatures. The question of an interrelation between the variations of radiation balance elements, the circulation and air temperature of the region is discussed.

OA25/ST2 Open session on the middle atmosphere

Convener: Dameris, M.
Co-Convener: Krüger, B.C.

AIRCRAFT BASED IMRMS MEASUREMENTS OF ACETONE AND OTHER ORGANIC TRACE GASES IN THE UPPER TROPOSPHERE AND LOWER STRATOSPHERE

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Acetone and other organics were measured in the upper troposphere and lower stratosphere during several aircraft campaigns in summer and winter covering latitudes from 30°N to 75°N. Acetone was found to be ubiquitious and to reach large volume mixing ratios (up to 3000 pptV) in extended air masses. Photochemical conversion of acetone leads to HO_2 and peroxyacetyl radicals. The latter in turn form HO_2 as well as PAN and organic acids. Thereby acetone potetially influences various other trace gases and aerosols.

MULTI-ANNUAL SIMULATIONS OF STRATOSPHERIC CONSTITUENTS IN A CLIMATE MODEL

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Two-year integrations are presented of a climate model with fully coupled and comprehensive stratospheric chemistry. The model has 49 levels between the ground and 0.1 mbar. The constituents are initialised with UARS data and 2-D model fields for January, and the model is integrated for two years. Comparisons are made with UARS monthly mean observations of the long-lived constituents O_3, HNO_3, N_2O_5, HCl, $ClONO_2$, CH_4 and N_2O and with total ozone measurements from TOVS. Preliminary results show that the model results are in reasonable agreement with the UARS data but with some quite important differences in detail. In particular, in agreement with other 3-D model studies, the model HCl values are generally too low, especially in the tropics. On the other hand model ClO values are in reasonable agreement with UARS observations. The early results also demonstrate that although the simulation of total ozone in the southern hemisphere is excellent throughout the year, the simulation of total ozone in the northern hemisphere is poor. The model transport will be investigated in further detail using conserved tracers to diagnose any potential weaknesses in the model meridional circulation.

SIMULATION OF THE WINTER STRATOSPHERE WITH ASSIMILATED TEMPERATURE FIELDS

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To study planetary waves during specific episodes (e.g. stratospheric warmings) mechanistic models frequently force geopotential heights derived from observations at the models lower boundary. But even when model initialization is perfect and radiation can be neglected, simulated fields deviate from observations, because vertical propagating waves interact with background winds. Here we couple a global mechanistic model over a closed altitude range with observations to study the lower stratosphere as a filter and source of wave activity. We use the Newtonian relaxation technique by nudging temperature fields. The main results due to forcing of different model layers (1000-100, 1000-10 and 1000-1 hPa) with daily global data from January, February and March 1989 are: forcing only tropospheric layers is insufficient to prognosticate the stratospheric circulation, while use of data from above 10 hPa gives no significant improvement. We conclude that the condition of the lower stratosphere influences the circulation up to mesospheric levels.

GRAVITY WAVE DIAGNOSIS OF THE GFDL "SKYHI" MODEL USING THE EMPIRICAL NORMAL MODE METHOD

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The importance of gravity wave forcing on the zonal mean state of the middle atmosphere has been recognized during the last two decades. In order to better understand and to quantify the specific role of gravity waves on the climatology of the stratosphere and mesosphere (and thus to be able to formulate dynamically significant gravity wave drag parameterization schemes), it is crucial to develop tools which can isolate gravity wave processes. In the present study, we propose a diagnostic method which uses pseudo-energy conservation to extract almost balanced quasi-monochromatic gravity and inertio-gravity wave modes (called Empirical Normal Modes) from meteorological fields. The analytical framework will be briefly presented, as well as some results obtained by applying the aforementioned method on the output of the GFDL "SKYHI" Troposphere-Stratosphere-Mesosphere General Circulation model (resolution of $1° \times 1.2°$) with no subgrid scale gravity wave drag parameterization. The analysis shows that gravity wave coherent structures emerge mainly just above the tropopause, and that a possible link between the breaking level of the waves and an imposed vertical mixing scheme based on a low Richardson number in the "SKYHI" model might exist.

INFLUENCE OF THE QUASI-BIENNIAL OSCILLATION ON THE EVOLUTION OF TRACER FIELDS IN THE EQUATORIAL STRATOSPHERE

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Stratospheric aerosol data as well as HF and CH_4 obtained by the HALOE instrument on the UARS satellite indicated that transport from the tropical stratospheric reservoir to midlatitudes is strongly dependent on the equatorial QBO. The time-latitude sections of normalized aerosol, HF and CH_4 show clear sign of sinking at the equator with time. The equatorially-asymmetric distribution of aerosol reveals the interannual variability of annual oscillation in the subtropics. The meridional divergence and convergence related with the equatorial rising/sinking motion seems to be crucial in influencing this variability. At the equator the vertical convergence (divergence) points were located in HF and CH_4 fields and compared with points of maximum westerly (easterly). The divergence points are especially in good agreement with the points of easterly maxima which is another evidence of role of the secondary meridional circulation in equatorial transport.

STRATOSPHERIC VACILLATIONS IN A GENERAL CIRCULATION MODEL

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To study the variability in the winter stratosphere we have performed a series of perpetual January experiments with Arpege, the French community general circulation model.
On the winter hemisphere temperature anomalies develop in the mesosphere and slowly descend through the stratosphere until they dissipate in the lower stratosphere. The variability is oscillatory with a time scale of about 50-100 days and show a vertical dipole structure: a warm lower stratosphere coincides with a cold upper stratosphere. Positive or weak negative values of the Eliassen-Palm flux correlates with accelerations of the zonal wind, inferring that the warmings are driven by interactions between the zonal mean and resolved eddies.
Variability on this time scale is not apparent in the troposphere. To assess the influence of tropospheric transience we have performed experiments with time independent tropospheres with different strength of the eddies. Although the transient wave forcing from the troposphere is absent vacillations persist in the stratosphere with unchanged time scale. Preliminary results indicate the existence of a critical wave forcing at the tropopause level which has to be surpassed for oscillations to exist. Furthermore, the time scale of the oscillations decreases with increasing wave forcing.
The behaviour described above resembles closely the behavior of the simple model of the stratospheric dynamics introduced by Holton and Mass.

Vertical Propagation of Rossby and Kelvin Waves in Stratosphere

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The stratosphere is dynamically very different from the underlying troposphere. Baroclinic instability is virtually suppressed and disturbances are mainly forced from below. The stratification of the stratosphere acts as a filter removing the smaller scale disturbances and allowing only the longest waves to propagate out of the troposphere to great heights in the stratosphere. These waves with upward propagation may influence the flow at the great heights and the transport processes and so the advection of ozone that is very important in generating concentration anomalies. An upward propagation wave and interaction with zonal flow determine the quasi-biennial oscillation (QBO), too. This paper has discribed the behavior of the vertically propagating Kelvin and Rossby waves, trying to explain the connection between troposphere and stratosphere circulation . The amplitude and the dependence of the vertical velocities of the latitude are different for the Kelvin and Rossby waves and so these waves are internally connected to their interaction with the basic zonal state. The distribution of the vertical velocities is consistent with the currently accepted theories of the mechanism that excite the QBO: the flow is forced from the troposphere and that it involves interaction between upward propagating waves and the mean flow. In addition, the values of the vertical perturbation of velocities confirm idea that in equatorial stratosphere the vertically propagating Kelvin and Rossby waves can carry important fluxes of heat and momentum.

TWO-COLOR LIDAR OBSERVATION OF A NOCTILUCENT CLOUD AT ALOMAR

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Two lidars, located in the ALOMAR observatory (69.3°N, 16.0°E) near Andenes/Norway, made simultaneous and common-volume measurements of an overhead noctilucent cloud (NLC) layer during the midnight period of August 12/13, 1995. The Rayleigh lidar and the ozone lidar provided measurements at wavelengths of 532 nm and 308 nm, respectively. During the observation time from 23:40 UT to 01:30 UT and 23:55 UT to 01:33 UT maximum backscatter ratios of 56 and 28 have been obtained for 532 and 308 nm, respectively. In the NLC layer, the ratio of volume backscatter coefficients ß(308)/ß(532) increased from 4.3 to 5.1 for altitudes from 81.8 km to 83.6 km. Applying standard Mie-theory and assuming a lognormal particle size distribution, these ratios imply modal radii of the NLC particles between 15 nm and 45 nm for values of the distribution width between 1.2 and 1.6 near 82.7 km altitude, with somewhat smaller particles above and larger particles below.

MID-LATITUDE NOCTILUCENT CLOUD OBSERVATIONS BY LIDAR

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Regular zenith-directed Rayleigh lidar soundings at Juliusruh (54.63°N, 13.38°E) in summer 1995 and 1996 indicated the presence of overhead noctilucent clouds (NLC) during four nights in June. For three of these nights, NLC were also sighted visually near the northern horizon. For one of the lidar-observed NLC events in 1995, temperature profiles were obtained immediately prior to the appearance of the NLC. These observations show at 81 km a strong cooling of about 30 K within two hours. The wind velocity and direction during the NLC events were inferred from daytime common-volume MF radar wind measure-ments. During the occurrence of the NLCs in 1995 the interpolated MF radar wind was south-westwards directed with velocities between 9 - 32 m/s. In July 1996 another overhead NLC was recorded by a zenith-directed lidar at 770 nm combined with a visual observation near the northern horizon at Kühlungsborn (54.12°N, 11.77°E). Different from high latitudes, NLCs at mid-latitudes can be observed by lidar in total darkness. Therefore, mid-latitude observations have the advantage to allow a characterisation of NLC particle size distributions and particle densities even with comparatively simple, multi-color lidars.

CORRELATIONS OF STRATOSPHERIC O_3 AND N_2O OVER THE SOUTH POLE FOR TWO QUASI-ANNUAL CYLES

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Millimeter wave spectroscopic measurements of stratospheric O_3 and N_2O over the South Pole have been performed for two 11-month periods: (1) February 1993-January 1994 and (2) January-December 1995. Strong similarities exist between the two quasi-annual cycles for both O_3 and N_2O. A double-peaked profile dominates O_3 vertical distribution in both years. N_2O observations show similar atmospheric descent rates during fall and winter. During springtime warmings, the O_3/N_2O ratio shows a tight coupling between O_3 and N_2O around 20 km, as transport creates the low altitude O_3 peak. A rapid and systematic decrease of the O_3/N_2O ratio during summer in the 25-30 km region (while N_2O is essentially stable) supports the increasingly dominant role of photochemistry in producing the vertical profile for O_3 above $\sim$ 25 km while leaving a transport-produced layer with a relatively large mixing ratio below $\sim$ 25 km. The resulting double-peaked O_3 distribution, which persists for many months, can alter the normally negative correlations between O_3 and N_2O in the lower and mid stratosphere, although in measurements of the N_2O/O_3 ratios for polar air, these perturbations have often been taken to be a hallmark of catalytic ozone depletion by chlorine.

OBSERVATIONS OF INTRASEASONAL OSCILLATIONS IN THE HIGH-ATITUDE AIRGLOW

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Observations of fluctuations in the night-airglow emissions from excited hydroxyl (OH), molecular oxygen (O2) and atomic oxygen (OI) have been used to infer the parameters of gravity, tidal and planetary-wave oscillations near the mesopause by many authors. In this study, the near-infrared (1000-1600 nm) Meinel bands of OH were observed along with the 762 nm Atmospheric band of O2 and the 557.7 nm green line of OI from a ground-based observatory outside of Stockholm, Sweden (59.5N, 18.2E). The nightly averaged OH temperature, as well as the nightly averaged radiance of the OH, O2 and OI emissions, all show clear evidence of distinct oscillations in the 60-70 day period range. In addition, the phase of the OH oscillations are nearly 90 out of phase with those displayed by the O2 and OI emissions. We will present the analysis, identification and seasonal evolution of these oscillations. In addition, we will suggest possible mechanisms for the generation of these high-latitude oscillations, which are strikingly similar to those seen in the equatorial mesospheric and lower thermospheric wind field.

WAVE STRUCTURE AND CORRELATION OF THE THERMODYNAMICAL PROCESSES IN THE MIDDLE AND LOWER ATMOSPHERE

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It is studying in the paper the problem of correlation of thermodynamical processes in the middle atmosphere. We have used as an initial data the simultaneous mean-daily values of thermodynamical parameters, measured in the Kazan University by the methods of temperature (troposphere, including tropopause) and meteor (upper mesosphere - lower thermosphere) sounding during the main and transition seasons of 1994 year.

Based on the analysis of the thermodynamical parameters temporal variations in the troposphere, tropopause and in the height region of upper mesosphere - lower thermosphere, there were revealed coherent structures of tne wave disturbances in the spectrum's interval corresponding to the planetary waves time scales. This structures are displaying the height and seasonal dependence. It was founded the active influence of the tropopause and mesopause on the coherence of analysed wave structures.

AN ESTIMATE OF THE QBO IN WATER VAPOR CONCENTRATION AND TRANSPORT IN THE QBO DOMAIN IN GCM EXPERIMENTS

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In order to study the relationship between the QBO and the general circulation, GCM experiments have been performed, using the ECHAM4 T42-L19 model, where the QBO was assimilated by a linear relaxation technique. The QBO modifies firstly the temperature above the tropical tropopause, hence also the water vapour content that may pass the tropopause, and secondly the vertical transport velocity by the secondary meridional circulation. Thus the upward transport is about 0.08 mm/s slower during westerly QBO-phase than during the opposite phase. The QBO signal found in the specific humidity on 50 hPa at the equator has an amplitude of 0.04 ppmm which is about half of the signal caused by ENSO in this model. The strength of the QBO signal is limited by the time scale of the QBO because the equilibration of the specific humidity has a much longer timescale. The combination of QBO and ENSO creates low frequency variability. The results are limited by the low vertical resolution and the neglect of photochemical processes.

MIDLATITUDINAL LOWER IONOSPHERE DISTURBANCES CAUSED BY NATURAL SOURSES

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There are given experimental data on natural disturbances (powerful earthquakes, the solar terminator, strong thunderstorms, solar flares and magnetic storms) having effects on the midlatitudinal ionospheric D-region parameters, characteristics of partially reflected (PR) signals and radio noise at f= 2-4 MHz. There are investigated parameters of the wave disturbances (a character, type, periods, durations and velocities) arising over these periods in the D-region. Our investigations were carried out by a PR technique within 1977-1994. The measurements of PR signals and radio noise were made under different heliogeophysical conditions ; the observation durations being minutes-hours-days; ~200 samples covering each source of the disturbances.

ELECTRON COLLISION FREQUENCY VARIATIONS IN THE LOWER IONOSPHERIC D REGION DURING MAGNETIC STORM

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Using a partial reflection technique it was found increasing of the electron collision frequency by more than 50% at the lower ionospheric D-region (Z<70 km) at the time of precipitating charged particles during magnetic storms. Our observations have been made during 3 magnetic storms in 1984-1985 in the vicinity of Kharkiv. The precipitation of charged particles was observed during 3-7 days after the magnetic storms. At these events there were observed intensive partially-reflected signals from the heights of 55 <Z< 70 km. It was found the electron density to become several times larger. The paper presents calculations of flow intensities of precipitating charged particles and ion-production velocities, made for these heights.

NUMERICAL EXPERIMENTS IN STRATOSPHERIC DYNAMICS

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The dynamical stratosphere can be modelled by the primitive equations with a suitable radiation scheme and an idealised forcing near 100mb (the latter representing tropospheric disturbances). Such a model has been written using isentropic coordinates and potential vorticity as a prognostic variable, making it ideal for the study of dynamics. Experiments have been carried out in perpetual January conditions with an initially zonally symmetric stratosphere. Various amplitudes of wave one forcing have been applied to the winter hemisphere. In all cases, except for low amplitude forcing, there is an initial erosion of the polar vortex before a quasi-periodic regime is entered. This regime consists of the formation of a series of anticyclones and their eastward advection around the polar vortex to a prefered location. These anticyclones decay but sometimes a low resolution vortex merger occurs between successive anticyclones. Similar behaviour has been observed in the real stratosphere during sudden warmings. It is interesting that the model continues the quasi-periodic regime for the duration of the model run, hundreds of days after the lower boundary forcing became steady. Results from further experiments with a full seasonal cycle will also be presented.

SIMULATION OF THE DYNAMICS AND CHEMISTRY OF THE POLAR VORTEX DURING THE WINTER 1995/96

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In the winter 1995/96 temperatures below 195 K, the conventional threshold value for PSC-I formation, were observed in the lower stratosphere between mid December and the begin of March. The low temperatures were caused by tropospheric anticyclones, which are usually accompanied by a high cold tropopause and low ozone values in the lower stratosphere. The combined effect of dynamics (elevated tropopause and advection of ozone poor air) and chemistry (chlorine activation due to heterogeneous chemistry taking place on the surface of PSC's) led to the evolution of minima in total ozon, the so called mini-holes. The strongest ozone destruction with total ozone values near 200 DU was observed in March over northwestern europe.
The aim of this study is to investigate the dynamical and chemical processes and their interaction during this episode. A threedimensional mechanistic model of the middle atmosphere covering the altitude range from 0 to 150 km, which is coupled with a chemistry and a transport module, is used to simulate the period from December 95 to April 96. The data for the temperature field, used to force the model at the lower boundary region are taken from ECMWF analyses. The main results will be presented and compared to data derived from satellite measurements.

ON THE SPECTRAL DECOMPOSITION OF STRATOSPHERIC FIELDS

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Spherical harmonics are used as a basis for the decomposition of stratospheric geopotential and temperature fields. The last twenty years period from 1976 to 1996 is analysed both on the monthly and daily values on 200, 100, 50, 30, 10 hPa levels. The aim of the study is to compare the changes of the principal wave components with respect to the changes of some circulation patterns (global circulation indices). Special attention is given to the interannual variability with special emphasis to the QBO, ENSO, solar cycles, volcanic activity etc. as well as to the analysis of annual course changes.

DEVIATIONS BETWEEN DIFFERENT METHODS FOR THE DETERMINATION OF THE AGE OF STRATOSPHERIC AIR AS CONSTRAINT FOR MIXING INTO THE POLAR VORTEX

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The age of stratospheric air is determined through measurements of the mixing-ratio of a trace component with a long atmospheric lifetime and a well known increase in the troposphere. Species like CO_2, SF_6, CF_4, C_2ClF_5 and C_2F_6 have been used for this purpose and are expected to yield consistent results. For the mid-latitudes this appears to be the case. At altitudes above 20 km inside the arctic polar vortex we find significantly higher ages for the perfluorinated compounds than for CO_2. We present evidence that these inferred differences in age are not due to destruction of perhalogenated substances in the upper stratosphere but result from the mixing in of CO_2-rich air into the vortex. Our data from the EASOE-winter 1991/92 can be used as a new constraint for exchange processes through the walls of the vortex.

GROUNDBASED MICROWAVE DETECTION OF WATER VAPOUR AND OZON AT 51°N

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Groundbased microwave spectroscopy is well suited for monitoring of the vertical distribution of middle atmospheric trace gases in that it provides accurate spectra of the molecular microwave emission. Due to its pressure broadening it is possible to deconvolve the spectra into components of different widths and thereby to obtain mixing ratios as a function of pressure, which can be mapped on an altitude scale. Two microwave spectrometers have been developed at the MPAE and provide data of middle atmospheric water vap our and ozone since 1992. This first simultaneous long term local detection of w ater vapour and ozone gives information about the seasonal variablilty as well a s the interdependence of both gases. A system description will be given and results of the data analysis will be presented.

PARAMETERIZATION OF WAVE BREAKING IN A LINEAR MODEL OF STATIONARY PLANETARY WAVES IN THE STRATOSPHERE

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Linear Theory has proven sucessful in modeling the vertical and meridional propagation of stationary planetary waves in the stratosphere. Usually, in such models wave dissipation is implemented as Newtonian cooling and Rayleigh friction. Here we make use of a recently developed parameterization for planetary wave breaking (Garcia, 1991) in order to obtain an improved representation of wave dissipation in the neighborhood of critical lines. Although we keep the zonal mean basic state fixed, solving for the wave turns into a nonlinear problem, as the dissipation coefficient depends on the wave itself. The problem is solved iteratively. In contrast to the wave amplitude, the Eliassen-Palm flux divergence depends rather sensitively on the wave breaking parameterization. It is expected that the EP-flux divergence thus generated results in a new tool to diagnose the occurence of strong wave-mean flow interaction from the zonal mean basic state. As a test of its usefulness, the model is applied to various basic states which are known to enhance or suppress major stratospheric warmings.

INTERANNUAL VARIABILITY IN EQUATORIAL LOWER STRATOSPHERIC WATER VAPOUR AS OBSERVED BY HALOE

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The Halogen Occultation Experiment (HALOE), which flies on the Upper Atmosphere Research Satellite (UARS), has been operational for over five years and provides an excellent means of examining water vapour and other constituents in the middle atmosphere. The observational range of the HALOE water vapour channel extends down to approximately the tropopause. Since the water vapour that enters the lower tropical stratosphere from the troposphere is strongly influenced by the tropopause temperature, these observations provide information about the global structure and behaviour of the tropical tropopause. In a previous paper (Jackson et al (1996), submitted to Quart. J. Roy. Meteor. Soc.) three years of HALOE data were used to calculate multi-year seasonal averages of water vapour at levels close to the tropopause. In addition, the interannual variability of the water vapour distribution was discussed. Here, we extend this study of interannual variability using the more up-to-date HALOE observations that have subsequently become available, with particular attention being paid to the equatorial Indian and Pacific Ocean regions in boreal winter.

MESOPAUSE WINDS OVER CENTRAL EUROPE IN 1994 AND 1995 AS MEASURED WITH TOTAL AND PARTIAL REFLECTION TECHNIQUES

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To obtain continuous measurements of the upper mesosphere and lower thermosphere wind field over Central Europe, daily D1 LF wind measurements using commercial radio transmitters (on 177, 225 and 270 kHz) at the Collm Observatory of the University of Leipzig, and MF radar wind measurements on 3.18 MHz at the Juliusruh Station of the Institute of Atmospheric Physics are carried out. These observations, applying to a mean reflection point at 52° N, 15°E, provide the prevailing wind and the tidal wind components and are useful for investigations of the upper atmosphere climatology. Vertical profiles of the wind field parameters can be derived with the aid of combined wind and reflection height measurements. Here height-time cross-sections of half-monthly mean prevailing winds and the semidiurnal tidal wind components using the combined total and partial reflection wind measurements are given for the years 1994 and 1995.

PLANETARY WAVE ACTIVITY AT THE MESOPAUSE OBTAINED FROM LONG-TERM TOTAL REFLECTION WIND MEASUREMENTS AT COLLM, GERMANY

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Upper mesosphere and lower thermosphere wind profiles over Central Europe (52° N, 15°E) has been recorded automatically since 1983 by total reflection wind measurements in the low-frequency range at the Collm Observatory of the University of Leipzig. Daily analyses of the zonal and meridional prevailing wind at the mesopause (~ 95 km height) are investigated with respect to interdiurnal oscillations with periods ranging between 2 and 18 days that, as a first approach, can be regarded as a measure for planetary wave activity. A mean climatology of the years 1983 - 1994 is presented, showing the main patterns of the annual planetary wave activity. Long-period waves (> about 10 days period) are mainly present in winter, while the short-period waves (2-4 days period) are found in summer. Time series of planetary wave activity show a significant increase during the period regarded.

THE INTERACTION OF PLANETARY WAVES AND THE ZONAL MEAN CIRCUALTION IN THE LOWER STRATOSPHERE

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The dissipation of planetary waves in the stratosphere transports heat polewards and maintains the temperature above radiative equillibrium. Observational evidence shows that the majority of the wave activity is dissipated in the lower stratosphere where wave amplitudes are generally small and the dominant dissipation mechanism appears to be radiative damping. For a given wave forcing it is possible to derive the heating rate and hence an estimate of the mean meridional mass circulation. The wave propagation, and hence dissipation, depends on the mean wind profile and hence on the temperature structure. The non-linearity of the wave motions in the upper stratosphere make a full discussion of the interdepence of wave-propagation and changes in temperature structure extremely complicated. In the lower stratosphere, however, the wave amplitude is small and the propagation is dominated by the vertical component. This allows the essential characteristics of the dynamics to be described by a one-dimensional linear model. The model is used to investigate the competing influences of wave forcing, generated by a prescribed disturbance at 100mb, and radiative forcing, taken as Newtonian relaxation to a uniform meridional temperature gradient.

A PARTIAL DIFFERENTIAL EQUATION FOR THE ICE PARTICLE SIZE DISTRIBUTION AT THE POLAR SUMMER MESOPAUSE

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Assuming heterogeneous nucleation on meteoric dust and taking into account the Kelvin effect, a partial differential equation describing the time evolution of the ice particle size distribution in a moving air parcel is derived. The relevant time scales indicate that for radii between 1 and 100 nm, ice particle growth and decay by condensation and evaporation dominate over the effects of dust particle production, ice particle flux divergence and diffusion. Using a dust size distribution similar to that obtained by Hunten et al. (J. Atmos. Sci. *37*, 1342, 1980) as initial condition, solutions for given time variations of the air parcel temperature are computed and discussed.

VERTICAL STRUCTURE OF TEMPERATURE PERIODIC COMPONENTS BETWEEN 30-90 KM AND ITS COMPARISON TO 2-D NUMERICAL MODELLING

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Periodogram analysis procedure was used to reveal the character periods and amplitudes of temperature oscillations (lidar data) between 30 - 90 km (1979-93,Provence:44N,6E). Night mean data sets of lidars mesurements were transformed into simultaneous sets after interpolation. The results has shown the existance of wave motions for periods of the waves near by 5-7,10-14,25-30 and 40-50 days in winter and depressed periodic motions for summer. 2-D numerical modelling has revealed the possibility of these waves to penetrate from below during winter conditions.

SIMULATIONS OF THE STRATOSPHERIC FLOW REGIME DURING THE SOUTHERN FINAL WARMING

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The UGAMP Stratosphere-Mesosphere Model (USMM) is used to simulate the southern stratosphere final warming and test if changes in the external forcing affect the stratospheric flow regime. It is found that (a) the USMM simulation compares well with UKMO analyses; (b) the geopotential height wave-1 and wave-2 component patterns at 10 hPa, 60°S are sensitive to the nature of the tropospheric forcing in the model. The implications of these results on our understanding of the different mechanisms associated with the southern final warming are discussed. The potential for future work involving coupled chemistry/transport studies of southern winter and the southern final warming will also be discussed.

NOCTILUCENT CLOUDS INVESTIGATION FROM THE "MIR" SPACECRAFT

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Results of the regular visual observations of the noctilucent clouds (NLC) from the "Mir" manned orbital station are presented. We claim that there is no difference between the NLC and the polar mesospheric clouds (PMC). It is an indication of the relatively high water vapor concentration (over 10^{-5}) in mesopause over the whole Earth. The only source of vapor can be the mini-comets. We observed ten cases of NLC occurrence with very small horizontal dimensions (less than 100 km) and lifetime of only 0.5-3 minutes. It was the very first observations of the small-sized NLC and their detailed structure.The problems of genesis, climatology of NLC as well as relation of their occurrence with other cosmophysical phenomena are considered.

LIDAR MONITORING OF THE MIDDLE ATMOSPHERE TEMPERATURE STRUCTURE ABOVE TABLE MOUNTAIN (34.4°N) AND MAUNA LOA (19.5°N) BETWEEN 1988 AND 1996.

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Temperature profiles obtained with the JPL lidar systems operating at Table Mountain, California (TMF, 34.4°N, 117.7°W) and at Mauna Loa, Hawaii (MLO, 19.5°N, 155.6°W) will be presented. Regular measurements began at TMF in 1988 and at MLO in 1993. The 353 nm Rayleigh signal was used at both locations to retrieve the temperature between approximately 25-km and 90-km, and at MLO the N_2 vibrational Raman signal at 382-nm was used to extend the temperature measurement below 15-km. The observed stratospheric and mesospheric temperature fluctuations at various temporal and vertical scales will be reviewed. A semi-annual temperature oscillation is clearly observed above MLO between 25 and 90 km altitude and an annual cycle is observed below 25 km. Both annual and semi-annual cycles are observed above TMF. Gravity waves fluctuations in the stratosphere and mesospheric temperature inversions are also clearly observed at both locations, as well as a tidal signature at MLO above 60 km of altitude. Inter-comparisons with the CIRA 86 model will be presented. Important departures from the CIRA model are mostly observed above 55 km.

LIDAR OBSERVATIONS OF MESOSPHERIC TEMPERATURE INVERSIONS AT TABLE MOUNTAIN (34.4°N) AND MAUNA LOA (19.5°N).

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Strong inversions in the vertical temperature gradient (from negative to positive) are frequently observed in the mesosphere. These so-called "temperature inversion layers" have mainly been observed near 70-km altitude for winter mid-latitudes using Rayleigh lidar and satellite measurements. Temperature inversions near 80-km altitude have also been observed by satellite measurements at lower latitudes a at the equinoxes. Several mechanisms have been proposed to explain their formation, involving such various processes as the breaking of gravity waves, tides, and chemical reactions. Recent results, using temperature measurements made by the Jet Propulsion Laboratory (JPL) lidar systems, located at the Table Mountain Facility (TMF, 34.4°N, 117.7°W) and Mauna Loa Observatory (MLO, 19.5°N, 155.6°W) are presented. The 1988-96 climatology of the inversions above TMF shows a strong annual cycle in their amplitude (temperature at top - temperature at bottom), with a maximum in winter. The mean altitude of the inversions is about 70-km. The 1993-96 climatology above MLO shows a strong semi-annual cycle, with a maximum amplitude in April and October. These inversions are located about 75 to 80-km altitude, i.e., higher than the winter inversions observed at TMF. The results, for both locations, are in good agreement with the climatologies previously developed using lidars at other locations and satellite measurements.

EVALUATION AND OPTIMIZATION OF LIDAR TEMPERATURE ANALYSIS ALOGORITHMS USING SIMULATED DATA

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A computer program has been to evaluate the accuracy of the Rayleigh and Raman lidar temperature analysis. The evaluation and the optimization of the algorithms can be performed for various instruments, given their characteristics. The JPL and CNRS temperature algorithms have been tested. Significant improvements to these algorithms were made using the results from the simulations. The program creates simulated data, at different processing levels, as if they were obtained by real measurements, but starting with a known original profile. The simulated data are then processed and the results are compared to the original profile. Various sources of error or inaccuracy met in the analysis processing are reviewed, such as smoothing, density normalization, altitude determination, and background correction. Comparisons of results obtained with older and more recent algorithms are finally presented showing that such simulations could be used in the future for other temperature lidar instruments, notably within the Network for Detection of Stratospheric Change (NDSC).

IONOSPHERIC BURSTS INDUCED BY SOLAR X-RAY FLARES

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Observations of the ionospheric radionoise were carried out with high sensitivity near 1.E-26 W/m2Hz and power resolution less than 1 angular degree on the wavelength 3 m. The following results were obtained: 1. The majority of the ionospheric radionoises events are the short (dt<1s) impulsive bursts. 2.Probability of the bursts increased up to 10-100 times after and during the solar X-ray flares. 3. The increase of the X-ray flux caused the increase of the burst density in higher degree than it's amplitude. 4. Sizes of the generation source are limited to several kilometers cubed on the height 60 km. 5. Several significant bursts existed (near 1.E-22 W/m2 Hz). Their sources' sizes were more than 10 kilometer cubed, but these events were rare (one per hour). These bursts are explained by existence of the discharges in the upper atmosphere.

MESOSPHERIC TEMPERATURES MEASURED BY THE CRISTA EXPERIMENT

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Thermal emissions of several trace gases have been measured by the CRyogenic Infrared Spectrometers and Telescopes for the Atmosphere (CRISTA) instrument. CO_2 emissions were converted to height profiles of atmospheric temperature. Respective results with emphasis on the mesosphere will be discussed and maps of global temperatures will also be presented.

The tropical stratopause in UKMO stratospheric analyses: evidence for a 2-day wave and inertial circulations

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The 2-day wave is a westward-propagating planetary wave which appears recurrently in the summer subtropical upper stratosphere. Evidence is shown of a 2-day wave in the UK Meteorological Office stratospheric analyses during January. Spectral analysis of dynamical quantities and off-line transport of water vapor by the assimilated wind fields are carried out. By contrast, the winter subtropics are characterized by mixing on less-than-planetary scales. Water vapor is mixed turbulently into gyres, and filaments are drawn out the southern hemisphere.

A comparison is drawn with water vapor along-track observations from the MLS instrument aboard UARS. A possible mechanism connecting the initiation of the austral 2-day wave events to strong planetary wave activity in the winter hemisphere is proposed.

Laminae in ozone, water vapor, nitrous oxide, methane and halocarbons over mid-latitudes

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A series of balloon flights were conducted in March 1993 from Aire-sur-Adour in southern France, aimed at making in-situ measurements of a variety of trace gases within the polar vortex during a dynamically active period. Meteorological analyses indicate that the balloons were launched when the vortex edge was passing aloft. These mid-latitude balloon flights revealed coincident laminations in ozone, water vapor, and long-lived tropospheric source gases, such as nitrous oxide, methane. halocarbons. Using several sets of meteorological analyses and trace constituent data derived from the UARS observations, isentropic fine-scale distributions of such tracers are produced. Interleaved, slanting sheets of mid-latitude and polar air. hence of different trace gases content, are shown to give rise to the profile lamination in the vortex edge region.

SENSITIVITY OF THE MIDDLE ATMOSPHERE TO CL-BR LOADING STUDIED WITH A THREE-DIMENSIONAL CHEMICAL-TRANSPORT MODEL

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The chemical composition of the middle atmosphere and its sensitivity to Cl and Br species time variations are studied with a chemical-transport model (CTM) including a fully interactive microphysical code for aerosol formation and evolution. The model is used to study the long term variability of the atmospheric chemical composition in two scenarios: in the baseline case the surface fluxes of longlived species follow the indication of the Montreal protocol and the successive Copenhagen amendment. The perturbed case is that of the hypothetical CFC emmission expected without the Montreal protocol ('free-market'), with a tropospheric chlorine loading predicted for the year 2000 of about 9 ppbv, instead of less than 4 ppbv in the 'Montreal case'. The time-dependent model simulations are performed from year 1970 up to 2000, including the major SO2 volcanic perturbations during this period and studying the effects of the eruptions on aerosols and ozone. The baseline simulation shows the formation of the ozone hole during mid 1980's and a significant global ozone decrease since late 1990's. The limitation of CFC emissions enforced by the Montreal protocol produces a slight ozone recovery after 1996. In the 'free-market' case the prediction is that of a more dramatic ozone hole with constant deepening from 1970 to 2000 and a global ozone depletion of 9 % in the year 2000 with respect to 1970, compared with 3 % in the baseline case.

STUDY OF LEE WAVES BY MST RADAR OVER NORTHERN SCANDINAVIA

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A campaign to study mountain lee waves using MST radars, backscatter and ozone lidars in Kiruna and Andoya and the ALIS camera system in Kiruna will take place during winter 1996/1997 (from December 27 to February 2). The instruments are located above the polar circle and on both sides of the Scandinavian mountains. This experiment will analyse the influence of the lee waves in the stratosphere on the formation of Polar Stratospheric Clouds (PSCs). This poster will concentrate on the ESRAD MST radar observations from Kiruna. The MST radar is located at ESRANGE [68. °N, 21. °E] to the east of the Scandinavian mountains and operates at 52 MHz. It has 72kW peak power (12 modules of 6 kW each) and a square antenna array consisting of 140-5 element yagis. The yagis can be grouped in different ways and the signal channelled to 6 different receivers. Winds, velocity perturbations associated with waves, and characteristics of turbulence will be studied from 1 km up to 10-15km altitude, with a resolution of 300 m. The observations will be used to characterise the mountain lee waves and their dependance on topography and synoptic conditions (background winds and temperatures).

SENSITIVITY STUDIES OF THE DYNAMICAL COUPLING OF CHEMISTRY AND RADIATION IN A 3-D CIRCULATION MODEL OF THE MIDDLE ATMOSPHERE

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A detailed chemistry scheme for the middle atmosphere up to 70 km has been added to the 3-D circulation model KASIMA. KASIMA solves the set of the meteorological primitive equations in spectral form and includes a physical parameterization for the heating and cooling rates and a Lindzen type parameterization for gravity wave breaking. Using datasets of ECMWF analyses at 10 km for the lower boundary of the year 1992/93 the coupling of chemistry and dynamics by ozone is studied with two model versions: First the net heating rates are determined using a climatological ozone field; in the second version the ozone field is derived in the model itself by the chemistry and transport modules. The two model outputs are compared with respect to temperature and wind fields, but also the influence on the transport of chemical tracers is studied. Further the effects of initialization of the chemical species and the influence of different heating rate parameterizations will be discussed.

VARIABILITY OF THE CONCENTRATION OF NIGHT-TIME STRATOSPHERIC NO_3 IN VERTICAL PROFILES OBTAINED FROM BALLOON MEASUREMENTS. COMPARISON WITH MODELS

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Observations of night-time stratospheric species were performed by the AMON instrument on May 24, 1992, October 16, 1993, March 24, 1994 from Aire sur l'Adour, and on February 10, 1995, from Kiruna. AMON is composed of a UV-visible spectrometer and used the stellar occultation method. After inversion, the vertical profile of NO_3, as well as the vertical distribution of the extinction coefficient of aerosols, are obtained in the 15-39 km range.
These profiles are compared with results of a box model constrained by ozone and temperature measured by AMON. Large discrepancies between observations and models appear for the 1992, 1993 and 1994 profiles at mid latitudes, while the aerosol content, mainly coming from the Pinatubo ejection, was significant. Some peaks of concentrations, of a few km width, can be due to temperature variations in the middle stratosphere, but others peaks may involve some (unknown) heterogeneous reaction with aerosols. A better agreement is obtained for the 1995 flight at high latitude on the polar vortex.

MAS OBSERVATIONS AT 61.15 GHZ, ZPM MODEL PREDICTIONS AND A LOWER TEMPERATURE LIMIT AT THE MESOPAUSE

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The Millimeter-wave Atmospheric Sounder (MAS) on board NASA's shuttle mission ATLAS 3 (November 1994) measured emissions of molecular oxygen at 61.15 GHz along limb path scans. The data show Zeeman-splitting of the emissions in the geomagnetic field and the low pressures of upper stratosphere and lower mesosphere. The ZPM model indicates a possible method of direct interpretation of these data in terms of a lower limit of the temperature at the mesopause. Results from the ATLAS 3 mission will be discussed.

STRATOSPHERIC TRACE GAS DISTRIBUTIONS MEASURED BY THE CRYOGENIC INFRARED SPECTROMETERS AND TELESCOPES FOR THE ATMOSPHERE (CRISTA) EXPERIMENT

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The CRISTA instrument aboard the Shuttle Pallet Satellite (SPAS) was flown on STS 66 in early November 1994. About 50000 height profiles of atmospheric trace gas emissions (15 to 180 km) were measured during a free flying period of 7 days. An experiment description will be given and the global distribution of several measured trace gases (CFC11, HNO_3, $ClONO_2$, ...) will be discussed with emphasis on small and medium scale dynamical structures.

THE RELATION BETWEEN VERTICAL VELOCITY AND ECHO POWER OBSERVED WITH THE SOUSY VHF RADAR IN THE TROPOSPHERE

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The perturbations to the static stability (and hence to the radar reflectivity) and to the velocity in a vertically propagating gravity wave are correlated, and the sign of the correlation depends on the propagation direction. In this paper the wave-induced correlation between radar reflectivity and vertical velocity to explain the downward bias in long-term averages of the vertical velocity is tested. Observations at troposphere heights with very high time- and vertical-resolution have been carried out using the SOUSY VHF radar. It is found that the mean vertical velocity in the mid-troposphere (2.4-6.3 km) is downward (upward) when the perturbations to vertical velocity and to backscattered power over this height range are negatively (positively) correlated.

A COMPARISON OF THE DISTRIBUTION OF CHEMICAL TRACE SPECIES BETWEEN AN OFF-LINE AND A COUPLED ON-LINE 3-D CIRCULATION MODEL

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A detailed chemistry scheme has been included in the 3-D circulation model of the stratosphere KASIMA. The transport of the chemical species within KASIMA can either be studied off-line driving the model with ECMWF analyses or on-line by solving the set of primitive equations in spectral form.
The results of two simulations for the 1992-1993 northern hemispheric winter are presented. One integration has been performed using the off-line model with a T42 horizontal resolution and 21 levels up to 10 hPa. The other integration has been carried out with a coupled T42 version of the on-line model with 63 levels between 10 and 120 km. In the coupled version the chemical species are not only transported, but the derived ozone field is used in radiative transfer to calculate the net heating rates. The results show the effect of the different wind and temperature fields used in the integrations on the distribution of trace species, with emphasis on the partitioning of the nitrogen species.

THE LOWEST OSCILLATION'S MODE OF THE ACOUSTIC GRAVITY WAVES AND IT'S INSTABILITY IN NONISOTHERMAL ATMOSPHERE

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In this work we discuss the model problem about finding the lowest mode of the high frequency acoustic gravity waves. For analytical approximation the real altitude profile of atmospheric temperature we find an exact solution for altitude dependence on vertical speed of the atmosphere and an expression of the cut frequency w in the nonisotermal atmosphere. It shown, that the nonlinear waves absorption effects on the frequency w . In case when the waves propagates vertically the value w increases. On the basis of results of the solution of the model problem about finding the lowest mode of the acoustic gravity waves with w frequency we conclude that in nonisothermal atmosphere the cut frequency w can be smaller than Brunt-Vaisala frequency w . In this case the acoustic gravity wave instability can be possible. The estimation of this instability increment was obtained.

RESPONSE OF THE STRATOSPHERE TO CONSTANT EXTERNAL FORCING.

A. A. Scaife
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A primitive equation model of the stratosphere and mesosphere is used to investigate middle atmosphere flow under perpetual January conditions, with constant forcing from the troposphere. For low wave forcing, the model has steady solutions which are close to the solution with no wave forcing and radiative equilibrium. Above some critical wave amplitude the model has vacillating solutions, as found in quasi-geostrophic β-channel models truncated to zonal wave 1 (Holton and Mass 1976). These vacillations are associated with strong sudden warmings, showing that for the primitive equations, spontaneous warmings can be generated without pulses in tropospheric wave amplitudes. The dependence of the critical wave amplitude on wavenumber is also investigated. One feature of the current integrations not reported in the simpler models is a smaller amplitude oscillation in zonal mean wind with a timescale of a few days. This oscillation appears to be related to wave-wave interactions and the generation of higher wave numbers from zonal wave 1. Similarities between these idealised integrations and the observed stratosphere are also noted.

THE EQUATORIAL QUASI-BIENNIAL AND SEMI-ANNUAL OSCILLATIONS IN SSU ANALYSES.

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SSU geopotential height analyses, derived from satellite soundings of the stratosphere, show clear QBO and SAO signals. Three analyses are compared: geostrophic analysis of SSU height data interpolated to the equator, curvature relation applied to the SSU height data, and UKMO assimilated data. Both analyses of the SSU data underestimate the strength and duration of the westerly QBO phase but the curvature relation is the more accurate. Because the centred finite difference form of the curvature relation is almost identical to that for interpolated geostrophy but for a factor of 2 in resolution, we infer that resolution is the most important factor in analysing the strength and duration of the QBO westerlies. Differences between the assimilated data and simple analysis of SSU heights include the greater altitude of QBO wind maxima in the SSU analyses, leading to a weak vertical wind shear in these data. However, the westerly phase of the SAO is stronger and more accurate in the SSU analyses than assimilated data, presumably because the numerical model used in the assimilation process does not accurately simulate the westerly SAO phase; a common problem with GCMs.

THE OCCURRENCE OF OZONE MINI-HOLE EVENTS DURING WINTERTIME STRATOSPHERIC WARMINGS

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An ozone mini-hole is a synoptic-scale area of strongly depleted column total ozone amounts, which undergoes a cycle of growth and decay in direct association with tropospheric weather events. However, it is also known that stratospheric dynamics can have a significant impact on the depth and extent of mini-hole events. In particular, the position and intensity of the stratospheric polar vortex plays an important role. To investigate this, the dynamics associated with ozone mini-holes during periods of wintertime stratospheric warmings, together with their mean frequency and geographical distribution at these times, is analysed and compared with a general climatology of ozone mini-holes over the northern hemisphere based on Nimbus-7 TOMS data. The stratospheric warmings are classified into two types: those with a dominant wavenumber-1 structure, and those with a strong wavenumber-2 component. To illustrate mini-hole development in each class of warming, typical case-studies are chosen and results of Contour Advection calculations are shown to characterize the motion fields. Wavenumber-1 warmings exhibit a significant increase in mini-hole occurrence over the European region, with a corresponding reduction in occurrence over the N. American region, while wavenumber-2 warmings exhibit the opposite changes.

GROUND-BASED MICROWAVE MEASUREMENTS OF H_2O AND O_3 IN THE ARCTIC MIDDLE ATMOSPHERE

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Ground-based microwave measurements of middle atmospheric trace gases provide a cheap and effective way to collect data for local variabilities and long term atmospheric trends. At our institute we have developed high-resolution heterodyne spectrometers which we use to continuously monitor the emission lines of H_2O at 22 GHz and O_3 at 142 GHz. H_2O provides the major source for HO_x radicals which play an increasing role in the O_3 depletion reactions with higher altitudes. Furthermore it has an essential role in understanding the formation of NLCs. The measurements were taken at high northern latitudes (Andenes, 69.3°N) and represent the first groundbased water vapour data measured above the arctic circle. Furthermore it is the only simultaneous measurement of H_2O and O_3 at arctic latitudes. Our data covers the period from Nov 95 to May 96 (O_3) respectively Oct 96 (H_2O). Beside a description of our radiometer with the CTS backend we present profiles of both species that show annual and inter-annual variability.

Stratospheric nitric acid and total reactive nitrogen measurements by different balloon-borne methods

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Nitric acid (HNO_3) and total reactive nitrogen (NO_y) were measured at mid-latitudes within SESAME in October 1994 using balloon-borne *in-situ* (ion molecule reaction mass spectrometry = IMR-MS of MPIK; NO_y-chemiluminiscence detector = NO_y-CD of UN) and remote-sensing (infrared Fourier-transformation spectrometer = FTIR of LPMA) instruments. For the first time *in-situ* intercomparison measurements of HNO_3 and NO_y were performed by IMR-MS and NO_y-CD at the same location within a time span of less than one day. The obtained VMR profiles will be presented and compared with the FTIR data which were obtained two weeks later at the same location. The implications for nitrogen partitioning will be discussed.

VERTICAL PROFILES OF SULFUR HEXAFLUORIDE IN THE STRATOSPHERE: FROM FLASK MEASUREMENTS TO IN-SITU GASCHROMATOGRAPHY

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The concept of the „age of stratospheric air" has become an extremely important tool to gain further insights in dynamic processes like transport and mixing in the stratosphere. Sulfur hexafluoride (SF_6) is regarded as a powerful tracer to determine the age of stratospheric air samples with a high accuracy. However, only few stratospheric SF_6-data have been available so far.
Recent vertical profiles of SF_6-mixing ratios in the arctic stratosphere are presented, obtained from balloon-borne whole air sampling and subsequent gas-chromatographic analysis with electron capture detection. Furthermore, the concept of a new balloon-borne in-situ SF_6-chromatograph will be presented, which is being developed within the EU founded project „LITES". This chromatograph will be capable to determine stratospheric SF_6-mixing ratios with a time resolution of 1 minute.

MIDDLE ATMOSPHERE VARIABILITY IN THE UKMO UNIFIED MODEL

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The middle atmosphere variability of several multi-year runs of the troposphere-stratosphere configuration of the UKMO Unified Model (UM) is studied and compared with UKMO analyses and results from other middle atmosphere General Circulation Models (GCMs). The main features, capabilities and problem areas of the UM are discussed. In particular, it is shown that the UM produces a very good simulation of the stratospheric circulation and its seasonal evolution. Time series of 10 hPa polar temperatures show realistic behaviour in both hemispheres. The southern hemisphere winter polar night jet has a realistic magnitude and exhibits little interannual variability, while the northern hemisphere jet exhibits considerable interannual variability (as observed). In common with other middle atmosphere GCMs, the UM has a cold bias in the stratosphere and does not simulate the Quasi-Biennial Oscillation. Future work with the UM on the impact of the stratosphere on tropospheric climate will be discussed briefly.

FIRST RESULTS FOR OZONE VARIATIONS DUE TO SOLAR PROTON EVENTS DURING 21-ST AND 22-ND SOLAR CYCLES

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It is assumed that by penetration of solar cosmic rays (SCR) into the middle atmosphere the ozone is destructed. However we suppose that at certain altitudes ozone can be created as a result of chain ion reactions taking part in the stratosphere. In this investigation satellite data for ozone density in the atmosphere during SCR in 21-st and 22-nd solar cycles were used. The values of ozone concentration (partial pressure) were taken from profiles of the following heights: 25.5 km, 24.5 km, 23.5 km, 19.5 km, 18.5 km and 11.5 km. The orbits of the satellites passed latitudes from 30° to 90° N and longitudes from 20° to 40° E. Data for the high energy protons were taken from Solar Geophysical Data - Bolder, Colorado. Cosmic ray measurements obtained from the neutral monitor in Kiel, Germany were utilized also. The influence of solar protons from seven energetic intrervals from 4.2 MeV till 850 MeV were studied. As a result of statistical analysis direct cause-effect relationships between ozone creation and SCR at heights 18-19 km have been obtained.

ON DISRIBUTION OF AEOSOL PARTICLES IN TEMPERATURE STRATIFIED MIDDLE ATMOSPHERE

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At investigation of distribution of aerosols in the middle atmosphere the developed by authors stationary model of aerosol particles distribution in northern hemisphere was used. This model bases on the theory of suspended particles sedimentation in a turbulent temperature-stratified media and on monthly-averaged model of the main meteorological parameters of the earth's atmosphere in the points of standard geographical lattice. On the base of calculations from the model the altitude factors, seasonal and geographical ones, which influence on distribution of aerosol particles concentration, were investigated. Following laws was found: In the layers of atmosphere higher than 30 km seasonal variations of month-averaged values of aerosol particles concentration are more than in troposphere and in bottom stratosphere. These variations are more significant in polar areas than in equatorial ones. Concentration of aerosols is maximal in June and minimal in January. The summer's concentrations are in two times more than winter's ones.

INVESTIGATION OF ATMOSPHERIC GASEOUS AND AEROSOL CONTENTS ABOARD THE SPACE STATION MIR

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The principal characteristics of two optical devices (OZONE-MIR and ISTOK-1) operating onboard PRIRODA module are described. The OZONE-MIR spectrometer measures direct solar radiation at slant paths in the 0.26-1.02 um spectral range (~160 channels) during the occultation events. The ISTOK-1 spectroradiometer registers both the solar slant path radiation spectra and limb atmospheric radiation in the 4-16 um spectral range (about 60 channels). Information on the methods of interpreting the space measurement data from the above devices (radiation models, retrieval methods, information content of the measurements) is reported. Potential accuracy of retrieving the atmospheric gaseous (O_3, NO_2, H_2O, CH_4, HNO_3, N_2O, etc.) and aerosol contents is discussed. The results of the space measurements fulfilled over various terrestrial regions in 1996-1997 are analyzed.

LIDAR OBSERVATIONS OF TIDES IN THE MIDDLE ATMOSPHERE AND THE TIME PROJECT

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Rayleigh lidars can measure atmospheric tidal signatures in temperature, both in and out of the stratospheric tidal-forcing zone. Despite limitations imposed by noise, and the restriction to night-time measurements only, an analysis technique has been developed which can allow determination of tidal amplitudes and phases. Theoretical knowledge is helpful in distinguishing between diurnal and semi-diurnal tides. Tidal amplitudes and phases are presented from a number of lidar observation sessions. However, distinguishing between the presence of different tidal modes remains particularly difficult from single-site measurements. To overcome this problem, the TIME (TIdal Middle-latitude Experiment) project proposes to group together simultaneous atmospheric soundings in the northern-hemisphere middle-latitudes from several instruments including lidars, radars and OH photometers, etc. Besides direct tidal measurements, this project should also be able to contribute to global circulation models which include the propagation and forcing of tides.

METEOROLOGICAL INFLUENCES ON THE IONOSPHERE DURING THE WINTER 1989 - 1990

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Some meteorological disturbances on the ionospheric *D*, *E* and *F* regions during the period 1 November 1989 - 14 March 1990 are investigated. As source data used are: *i)* meteorological measurements in Sofia; *ii)* rocket data (profiles of the temperatures, pressure and winds) from Akhtopol station; *iii)* A1-method measurements of critical frequences f_0E, f_0F1 and f_0F2, minimal reflectance frequency $f$min, and boundary frequency f_0Es of the sporadic *E*-layer; *iv)* A3-method absorption measurements in the lower ionosphere by long and middle radiowaves. Complete statistical analysis (autocorrelation-, crosscorrelation-, Fourier-analysis etc.) is made of the considered data and the proper physical interpretation of the tropospheric-ionospheric disturbances is given.

EFFECTS OF SOLAR PROTON EVENTS ON ELECTRICAL CONDUCTIVITIES IN THE IONOSPHERE AND MIDDLE ATMOSPHERE

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A new model is created for the electric conductivities in the region 10 - 1000 km of the middle and upper atmosphere. The main goal in this work is to determine the sensitivity of the components of electric conductivity tensor in the ionosphere towards solar proton events (SPE) which are the most important manifestation of the solar activity. For this purpose we shall consider some of the greatest SPE of the 22-nd solar cycle (19 October 1989) and 19-th solar cycle (23 February 1956). We shall use the improved model for the computation of the electron production rate profiles and electron density profiles. We will use the expressions for the field - aligned, Pedersen and Hall conductivities, taking into account also the positive and negative ion densities in the middle atmosphere. This model is realized on Turbo Pascal algorithmic language. For the evaluation of the SPE effects are used ground and satellite measurements for the spectra of the solar cosmic rays. The components of the electric conductivity tensor are calculated for geomagnetic cut-off rigidity $E=10$ and 40 MeV. The main SPE influence on conductivities is localized at altitudes 20-100 km, which can increase until 2 orders (for $E=40$ MeV) and 3 orders (for $E=10$ MeV) in comparison with the quiet conditions.

SHEAR INSTABILITIES IN THE LOWER STRATOSPHERE AND ASSOCIATED VHF RADAR ECHOES.

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VHF radar is used to measure the wind velocity and radar echo power related to long-period wind perturbations, including gravity waves, which are observed commonly in the lower stratosphere and tropopause region, and sometimes in the troposphere. These wind structures have been identified as either inertia-gravity waves or mountain waves. At heights of maximum wind shear, imbalances are found between the echo powers of a symmetric pair of radar beams, which are expected to be equal; the largest effects are found for conditions of simultaneous high windshear and high aspect sensitivity. These power imbalances could arise from tilted anisotropic scattering layers - a result of, for instance, Kelvin-Helmholtz instabilities generated by the strong wind shears. Measurements of this type may indicate the creation of turbulent layers, and mixing, in the lower stratosphere.

MEASUREMENTS OF OZONE, NO2, BrO, OClO, AND IO OVER NY-ÅLESUND, SPITSBERGEN FROM 1995 TO 1997

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Measurements of total column and/or slant column amounts of BrO, OClO, IO, NO_2, and O_3 over Ny-Ålesund (79° N) made from late winter in 1995 to spring 1997 are the subject of this study. The trace gases were observed by ground based UV/visible absorption spectroscopy of sunlight scattered from the zenith sky and direct moonlight. Slant columns of the absorbers are derived by means of a Differential Optical Absorption Spectroscopy (DOAS) algorithm.

Diurnal, seasonal and year-to-year variation for all absorber will be presented and interpreted. Additional a comparison with model predictions will be shown. Another focal point is the discussion if IO is present in the stratosphere or not.

OA26 GNSS-based atmospheric profiling and imaging

Convener: Kirchengast, G.
Co-Convener: Hoeg, P.

SPACE-TIME TOMOGRAPHY USING GNSS

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Achievements in the field of middle-orbital satellite radiotomography (RT) of the ionosphere have lent impetus to studies of the nearspace environment by applying the similar technique using probing signals of GNSS. It is necessary to take into account the temporal dependence of the requied function, because high orbital satellites have a small angular velocities and recording periods are about 30-60 minutes. The application of the conventional RT approach (with no allowance for temporal variations) appears to show little promise. A new approach to space-time tomography is proposed and illustrated by examples. The appearance of one more variable—time increases the dimensions of the RT problem, i.e. the plane problem of ray tomography becomes three-dimensional. The rays intersecting such a three-dimensional structure would pass each in its own time. Phase and group delay measurements made with the help of GNSS allow quite accurate determination of the relative TEC (total electron content), but yield an unacceptable large error in determination of the absolute TEC. Hence, the approach involving difference of linear integrals (phase differences) can be of service when applied to RT of nearspace environment. A number of RT schemes of the ionosphere and nearspace environment by using GNSS are analyzed. The application of GNSS with ground-based receivers is promising in the case of time-space tomography. The results of numerical experiments are presented.

VALIDATION OF TROPOSPHERIC AND IONOSPHERIC GPS/MET SOUNDINGS

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Almost exactly two years ago, the first GPS occultation observations from the GPS/MET instrument on MicroLab-1 were obtained and inverted. Since then, over 60,000 atmospheric soundings have been collected. Several thousand of these soundings were taken during optimal conditions (Prime Times) when the orbiting GPS antenna used to make occultation observations was pointed in the anti-velocity direction, and the United States Department of Defense had turned off Anti-Spoofing (A/S). This presentation will focus on our analysis and validation of data collected during these Prime Times. GPS/MET retrievals will be compared with weather models, radiosondes, and other space based remote sensing systems. We are also developing algorithms for inversion of data collected during periods when A/S was ON and will discuss the quality of these results. Recently we have begun to collect data specifically for ionospheric soundings and will compare these data to iono-sondes and incoherent scatter radar data.

DIFFERENT APPROACHES OF IONOSPHERIC CORRECTIONS FOR GPS BASED RADIO OCCULTATION MEASUREMENTS ONBOARD CHAMP

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When applying radio occultation measurements of GPS signals onboard a satellite in low Earth orbit (LEO), ionospheric propagation effects have to be taken into account. The ionospheric effects can be reduced on different ways: by forming a linear combination of the measured carrier phases at L1 and L2 frequencies, by using a linear combination of refraction angles at these two frequencies and by computing the ionospheric contribution based on models and separate ionospheric measurements.

The difficulties in correcting ionospheric propagation errors result mainly from the fact that the simplifying assumption of equal ray paths, although commonly used in GPS techniques, cannot be hold for limb sounding due to grazing incidence conditions. Simulation runs based on suited models for atmospheric and ionospheric refraction are carried out to study the effect of different ionospheric correction approaches on the accuracy of the retrieved temperature profile. The results are closely discussed in relation to the radio occultation experiment onboard the CHAMP satellite. Preliminary results favourize the application of the bending angle correction method.

DIFFRACTIVE METHODS IN PROCESSING GPS/MET DATA

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Processing of the GPS/MET satellite data in order to reconstruct atmospheric parameters such as temperature, pressure and humidity fields, encounter difficulties resulting from multipath and diffractive effects in the lower troposphere. Multipath propagation of the radio waves arises due to complicated structure of the humidity field. Phase and amplitude of the electromagnetic field in a multipath area undergo strong oscillations due to interference of different rays coming to the receiver and cannot be processed by means of standard algorithms based on one-ray geometrical optics. We propose a method of deciphering of the ray structure of the field received, based on the diffraction theory and synthesis of aperture. The method was tested in processing of real GPS/MET measurement. A series of numerical simulations on the basis of the NCEP model was performed. In the numerical simulations, we calculated the diffracted field passed through the atmosphere and applied our method of deriving of the refraction angle which was compared with the refraction angle calculated in the geometric optical approximation. The simulation indicated that method works well for realistic atmospheric inhomogeneities.

IONOSPHERIC MODELLING BY GNSS DATA.

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The comparison of a number of ionospheric models, including IRI, with radio tomography (RT) reconstruction data and total electron content (TEC) satellite measurings data is carried out. It is shown that the model data essentially differ from experimental data of TEC and RT of cross-section ionosphere. In many cases there is a significant error in determination of the electron density maximum, the directions of the gradients of electron concentration are determined incorrectly. Moreover, a number of structural formations (troughs, wave phenomena, finger-like structures) are not reproduced by models. In general, there is no model now, which can equivalently predict space-time ionosphere structure with the necessary accuracy for calculation of radio wave propagation and practical application in navigation and communication. In the report we offer the development of a new class of models based on GNSS measurements and RT data. Now there are detectors able to register 10-20 satellites GPS/GLONASS simultaneously, that allow determination TEC and TEC difference in different directions. A new model, that has been adapted in quasi-real time (30-60 min) according to GNSS data, may be constructed using this data and the information about ionosphere provided by some traditional models. Principles of construction of regional and global models are considered. For most practical applications it is sufficient to place detectors at a distance of about 1000 km.

IMAGING THE IONOSPHERE USING THE TOTAL ELECTRON CONTENT GRADIENTS ESTIMA TED FROM GNSS DATA

M.Hernández-Pajares, J.M.Juan, J.Sanz and **M.Martínez-Garcia** (Research Group of Astronomy and Space Geodesy. Universitat Politècnica de Catalunya. Barcelona, Spain)

A new method to obtain accurate *images* of the ionospheric Total Electron Content (TEC) that consists on the integration of the spatial TEC gradients has been developed. These gradients are previously estimated from consecutive Global Positioning System (GPS) observations for different pairs station-satellite. The encouraged results given by this simple and fast method seems to indicate that this technique is a good way to obtain the TEC distribution in different scales. For instance, this technique has been applied to model the global TEC during 24th June 1995. The ionospheric *images* obtained are in agreement with other techniques as well as climatological models studying this part of the Atmosphere.

INVERSION OF GPS/MET DATA — PROBLEMS AND SOLUTIONS

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Practical aspects of GPS/MET data analysis are discussed which are decisive for the quality of retrieval products. We applied Abelian integral inversion of atmospheric bending angle data into refractivity profiles.

The problems of ionospheric correction and upper boundary handling of the Abelian integral are described by showing examples. A heuristic variant of statistical optimization was developed and applied to the bending angle above 40 km height. It involves topside bending angle profiles from a model atmosphere and stabilizes the inversion. Retrieved temperature profiles were compared to corresponding profiles available at (U.S.) UCAR and JPL servers (also produced by Abelian inversion). Large differences occur in some cases (5 K and more), probably due to different treatment of the upper boundary, data runaways and noise.

Furthermore, temperature profiles with wavelike structures at upper tropospheric and stratospheric heights are shown. Whilst the upper stratospheric structures could be caused by residual ionospheric errors, the periodic temperature fluctuations at heights below 30 km are most likely caused by atmospheric waves (vertically propagating large-scale gravity waves and equatorial waves).

HIGH RESOLUTION TEC MONITORING METHOD USING GROUND GPS DATA

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Usually the ionospheric electron content estimated from dual frequency Global Posisitoning System (GPS) observations is modelled in *absolute terms*, taken as unknowns the instrumental delays jointly with the electron densities or its gradients, which are considered constant over certain regions or *pixels*. This approach has the disadvantage to not use all the accuracy of the input data –the ionospheric combination, calculated from both the dual phase and code observations–. One source of this *lost of accuracy* are the integration time interval needed to merge the observations in order to have enough data to perform electron content estimates. Kalman filtering can be applied to improve the temporal resolution *connecting* batches of *boxel* electron content models. Other sources are the discretization error, in the case of pixel (*boxel* in 3-D) models, and the correlations between instrumental delays and electron content estimations under certains circumstances.

In order to overcome such limitations, in this paper we use the consecutive differences in time for the same pair station-satellite, *as input data*, to cancel the common bias terms as the instrumental delays and improve the temporal and spatial resolution of the model (30 seconds and 0.2 degrees respectively). Such resolution strongly suggests to apply this method to monitorize the Total Electron Content (TEC) variations during periods of geomagnetic activity.

END-TO-END GNSS OCCULTATION PERFORMANCE SIMULATION

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An "End-to-end GNSS Occultation Performance Simulator (EGOPS)" is currently under development as an international European effort. EGOPS is a software tool for integrated simulation of the GNSS–based radio-occultation technique from the satellites transmitting the signals (GPS and GLONASS systems) down to final data products like temperature and water vapour profiles. An overview on concept and structure of EGOPS is provided and exemplary simulator results are shown. Major aims of EGOPS are i) mission analysis and planning for generic satellites in Low Earth Orbits (LEOs) equipped with GNSS receivers (occultation shape, coverage, and statistics computations dependent on GNSS/LEO constellations and antennae field-of-views), ii) simulation of occultation observations (forward modeling of GNSS-to-LEO signal propagation through the atmosphere/ionosphere system plus effects of the observing system such as receiver noise and local multipath), and iii) processing of simulated or observed occultation data (from raw phase delays and amplitudes to atmospheric profiles). The basic EGOPS rationale is effective treatment of as many as possible relevant aspects of GNSS occultation by an integrated tool open for continuous improvements.

POSSIBILITY OF THE NEARSPACE ENVIRONMENT TOMOGRAPHY

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Modern occultation technique for atmospheric profiling has essential limitations. In many cases distant complicated protonosphere and ionosphere structures (in particular, layer formations, troughs, wave disturbations, etc.) influence greatly reconstructed profilies. A variant of atmosphere-ionosphere tomography using GNSS and the network of ground-based receivers is considered. It is necessary to take into account temporal variations of atmosphere and ionosphere because of small angular GNSS velocity. Using the network of ground-based receivers improves the horizontal resolution and the accuracy of reconstructed vertical profiles. Two-level satellite tomography variant (i.e, satellites with 600-1000km altitudes added to GNSS, for example, 4 additional middle-orbital satellites in GLONASS plane) has more opportunities. It is reasonable to use 2-3 frequencies of receiver-transmitter systems in the range of 150-800 MHz. Such a system with ground-based receivers allows realization of Atmosphere-Ionosphere-Protonosphere tomography. Using middle-orbital satellites allows realization of occultation technique for atmospheric profiling and getting quasi-tangent rays improving the ionosphere tomography results and also fulfilling protonosphere tomography. The ground-based receivers are necessary for atmosphere-ionosphere tomography. Computer simulation results showed that the receivers spaced by hundreds of kilometers are sufficient for most of practical problems.

PROTONOSPHERE-IONOSPHERE INFLUENCE ON ATMOSPHERIC PROFILING.

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The studying of near Earth space and, partially, atmosphere derives new opportunities from demonstration GPS/MET. We paid attention to the different factors that effect on accuracy of the atmospheric index refraction profile in the radio occultation experiment using signals from spaceborn GPS-GLONASS. We take into account: i) the radiowave refraction in propagation media - protonosphere-ionosphere-atmosphere; ii) the real trajectory measurement accuracy and opportutities of TOPEX/POSEIDON system; iii) the influence of reconstruction method (Abel inversion).

The estimation predicts that in many cases the complicated structures such as the trough, thin sporadic layers, wave phenomena, etc. significantly influence on reconstructing profile. The low spatial resolution leads to averaging of measured values, that could be the source of additional systematic errors. For example, it was found out by numerical simulations that the accuracy of obtaining atmospheric temperature profile in the present time is not better then 1K in hight region 10-30 km and profile could be distorted by reasons mentioned above.

INVESTIGATIONS OF COMPLICATED IONOSPHERIC STRUCTURES BY RADIOTOMOGRAPHY

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The results of tomographic reconstructions using the ray radiotomography (RT), diffractional RT and statistical RT methods carried out in last decade are systematized and represented. The basis of the experimental technique for satellite RT is discussed. The tomographic sections obtained contain a great variety of the recovered structures. The experiments performed showed that the trough assumes various shapes, its width, slope and depth vary within a wide range of values. With the help of RT it is possible to clearly observe various wave and quasiwave structures appearing in the perturbed ionosphere, "finger-like" structures, some exotic formations. Comparisons of experimental RT results with results obtained by means of other experimental technique (inozonde, incoherent scaterring radars) showed acceptable quality of RT reconstructions. Examples of reconstructed two-dimensional sections of isolated diffractive irregularities of kilometer dimensions as well as a reconstructed spectrum of electron fluctuations are given. The presented results show wide possibilities of RT for investigiations of different ionospheric structures. Possible geophysical interpretations of the results and various approaches to RT reconstruction are disccused.

A GLOBAL SNAPSHOT OF WATER VAPOR FROM GPS/MET

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Orbiting GPS/GLONASS receivers making occultation observations can yield profiles of refractivity from which water vapor can be derived in the lower to middle troposphere with a unique combination of vertical resolution, global distribution and insensitivity to clouds and precipitation. We will review the resolution and accuracy expected from such observations and present water vapor data derived from GPS/MET. To isolate the water vapor contribution to refractivity, the temperature field from the closest 6 hour ECMWF global analysis has been spatially interpolated to the locations of each occultation. Comparisons with radiosondes and ECMWF analyses will be made. A 2-D (latitude vs. height) climatological snapshot has been derived from a 2-week span of GPS/ MET data and will be compared to the ECMWF humidity field and the humidity climatology of Peixoto and Oort. Of particular note are the signature of the tropical Hadley circulation and biases between ECMWF and occultation humidity fields apparently related to the Hadley circulation. Further, the atmosphere below the 500 mb level is somewhat drier in general than the ECMWF humidity field. Some possible implications for the control of moisture will be discussed.

IONOSPHERE SPECIFICATION BY MEANS OF TOMOGRAPHIC EVALUATION OF GNSS OCCULTATION AND GROUND DATA

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Inversion of GNSS signals received onboard of a LEO satellite gives average height profiles of electron density in the Earth ionosphere of excellent quality. There are several possibilities to add information on the horizontal distribution of ionization over an angular range of ±30° from the occultation ray perigee.

We concentrate on possibilities for tomographic reconstruction based on the combination with ground reception of NNSS signals. This leads to a substantial improvement of the "ground based" tomographic reconstruction geometry. The average height profile can be used to construct background models ("initial guesses") necessary to start iterative reconstruction procedures. On the other hand it can be the basis for profile families joint together with polynomials in the horizontal coordinate. The coefficients of the polynomials are considered to be the unknowns in an overdetermined linear equation system solved by means of SVD ("parameter fitting tomographic reconstruction").

A third possibility is briefly mentioned too: inversion of a pixel value system based on SVD with constraints.

Result examples are shown with data from GPS/MET.

VALIDATION OF GPS/MET TEMPERATURE PROFILES AT HIGH LATITUDES

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Radio-occultation is a potential method for measuring atmospheric refractivity, water vapor content and temperature profiles. The most potential benefit of satellite-borne radio-occultation measurements to meteorological and climatological applications is in regions not coveraged by the present radiosonde station network. The number of measurements at latitudes above 60° provided by GPS/MET is limited by the inclination of the satellite orbit and thus the measured profiles are very seldom co-located with the existing measurement stations. Data and data processing algorithm validation in these areas can be best performed by comparing the retrieved temperature profiles with the results from a NWP model. In areas with poor measurement station coverage a difference between the resulting profiles may indicate that the NWP model would benefit from the radio-occultation data.

A set of GPS/MET measurements from latitudes above 60° N are processed with three types of inversion methods: Abelian, sequential ray tracing and generalized ray tracing. The retrieved profiles are compared with profiles from the HIRLAM weather forecast model at the time and location of the ray perigee. The performance and the sensitivity of the inversion methods are compared against the reference temperature profiles.

The TurboRogue Space Receiver III Occultation Instrument

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A high precision GPS science instrument, designed and built at JPL for the CHAMP and SAC-C satellites, will employ an optimal architecture for retrieving atmospheric and ionospheric profiles from a satellite in low Earth orbit (LEO). This new design is loosely based on the GPS/MET TurboRogue GPS Receiver which has provided continous, autonomous GPS occultations from the MicroLab-1 satellite since April 1995.

To meet very ambitious performance goals, the TurboRogue Space Receiver III (TRSR-3) uses a more powerful microprocessor, a new GPS signal processing VLSI chip, and up to four dual frequency antennas. Two or more of these antennas can be actively arrayed under software control to increase the signal gain in the occultation direction. An independent zenith pointing antenna allows highest quality precise orbit determination and more focused limb-pointing antennas greatly improve the signal-to-noise ratio of lower troposphere observations. Additional on-board signal processing algorithms allow rising and setting occultation data to be edited and compressed on-board to reduce data storage and down-link bottlenecks. Instrument design and in-orbit performance goals will be described.

ENHANCED VERTICAL RESOLUTION IN RADIO OCCULTATION EXPERIMENTS

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When comparing radio occultation measurements using the GPS/GLONASS system for atmospheric profiling to conventional measurement methods the resolution of the radio occultation method becomes an important factor. Traditionally the Abel transform inversion is used to retrieve the atmosphere profiles. Thus the vertical resolution will be determined by the size of the first Fresnel zone which is approximately 1 km for the radio occultation measurements of planet Earth. Fresnel diffraction theory for enhancing the resolution has been used extensively in analysing limb sounding data for other planets. For measurements of the atmosphere of planet Earth the Fresnel diffraction theory still applies, but because of somewhat different conditions the theory needs modifications.

The theory of Frensel diffraction when applied to radio occultation measurements of the Earth's atmosphere and numerical testing of the theory will be presented. The results indicates that an enhancement of the vertical resolution with a factor of ~ 5 will be possible. Suggestions to and examples of further development of the method will be presented.

THE ESA METOP PROGRAM

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The European Space Agency (ESA), has a long experience in the development of geostationary meteorological satellites, the first of which (Meteosat) was launched as early as 1978. Similarly, ESA has been successful in the development and operations of the polar remote sensing satellites ERS-1 and ERS-2 embarking mainly radar based instruments. The immediate plans of the Agency include the preparation of the multi mission ENVISAT-1 to be launched in 1999, and of two new series of meteorological satellites (MSG and MetOp), the latter in cooperation with the European Organization for the operational exploitation of meteorological satellites, EUMETSAT. The MetOp satellites, the first of which is to be launched in 2002, will be the European contribution to the world meteorological polar satellite system, as they will replace the satellites flying in the morning orbit, provided by the U.S. until the year 2001. MetOp will embark similar instruments to the ones flying in the NOAA satellites, plus European advanced instruments. The main objectives of the MetOp satellites is to provide data for operational meteorological applications and climate monitoring. The payload includes instruments geared to give information on the atmospheric temperature and humidity profiles, essential for weather forecasting. One of such instruments will be the Global navigation satellite systems Receiver for Atmospheric Sounding GRAS, which uses the radio-occultation technique to infer the atmospheric refractivity, and from there, calculate atmospheric temperature, moisture and pressure. The synergetic use of the wealth of data provided by MetOp is expected to contribute to the improvement of meteorological and other applications, as well as to many areas of Earth Sciences research.

4-*D* DISTRIBUTION OF THE IONOSPHERIC ELECTRON DENSITY USING GPS/MET AND GROUND BASED RECEIVERS

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We have analyzed data retrieved during a day from 168 stations in the IGS network and from the Medium Rate Occultation database at UCAR. The data has been processed using GIPSY in order to obtain aligned phases. The IGS network data has then been analyzed using algebraic reconstruction tomography with a Kalman filter, and the GPS/MET phase data has been processed to yield Doppler-shift bending angles, which have then been used to yield profiles of electronic density via the Abel transform.

In this paper we present the analysis of our data in terms of a 4-*D* global ionospheric model.

ANALYSIS OF GPS/MET DATA AND ERROR ESTIMATION WITH DISCRETE MATRIX INVERSION

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The retrieval of atmospheric profiles from GPS/MET data using a matrix inversion formulation is shown.
The GPS/MET experiment provides data of phase path increases due to the refraction of radio waves by the neutral atmosphere and the ionosphere. In the data processing from phase measurements to atmospheric bending angles a heuristic variant of the statistical optimization approach is involved (recently developed by Hocke et al., 1996; paper in this session).
Refractivity profiles are retrieved by the application of matrix inversion, the matrix constituting a numerical implementation of the Abelian Inverse Transform operator. Density, pressure and temperature profiles are then calculated employing the standard dry-air formulae.
Tests with simulation data and comparison with Abelian integral inversion retrievals from GPS/MET data show the good quality of the retrieved atmospheric profiles.
Preliminary results of comparisons between GPS/MET temperature profiles and corresponding ECMWF model profiles are presented.
Advantages of the matrix inversion retrieval are the ability to invert the full data set and the feasibility of systematic error propagation analysis by using covariance matrices.

GPS-CLIM: A SMALL CONSTELLATION FOR GPS LIMB SOUNDING

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Long-term averaging of GPS occultation data promises to yield atmospheric measurements of unprecedented absolute accuracy. A constellation of six orbiting occultation receivers can achieve a refractivity precision equivalent to 0.1 K in temperature within a climate region corresponding to 1/30 the earth's surface, with just a few weeks of data. This offers perhaps the most promising approach yet to detecting and discriminating among subtle climatic signals, which may amount to a few tenths of a Kelvin average temperature change per decade. To avoid confounding true climate signals with aliased diurnal and seasonal effects, global sampling must be rigorously controlled, implying a constellation with strictly defined configuration. GPS-CLIM (for "climatology") is a proposed constellation of six microsatellites now under review for NASA's Earth System Science Pathfinder Program. The principal science objective is to test and refine global climate models. Designed by Spectrum Astro Inc, the 10-kg, notebook-size "CLIMsats" can be packed into the secondary payload space on such launch vehicles as the Delta II, Taurus, and Pegasus. To achieve the required uniform global coverage, the mission will distribute the six satellites about two orbit planes, using two separate launches three months apart. The satellites will be made large-ly with commercial grade parts to minimize cost. Future CLIMsats can be built and launched for less than $1M each. This opens up the possibility of low-cost future expansion of the constellation to dozens of satellites.

OA27/ST14 Global ozone

Convener: Hirschberg, M.-M.
Co-Conveners: Fabian, P.; Krivolutsky, A.A.

DO THE GLOBAL WINTER STRATOSPHERIC WARMINGS INFLUENCE ON THE TOTAL OZONE CONTENT OVER EAST SIBERIAN REGION?

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The East-Siberian region is the area of special interest for the global distribution and temporal variation of ozone due to climatic peculiarities and record low ozone values during some winters. Using daily means of the total ozone during 1979-1992 period and superposed epoch method the role of the global and local winter stratospheric warmings in producing of total ozone deviations from the long - term means is evaluated. The systematic satellite-aboard measurement's database (TOMS, NIMBUS-7) was used for this analysis. The calculations were carried out for Irkutsk (52N, 104E) and for some points along the Irkutsk meridian. We have found that the ozone response intensity and nature depend on the latitude and stratospheric warming type (minor, major, final).

RELATION BETWEEN SURFACE OZONE AND NATURAL DUST TRANSPORT IN THE SOUTH EUROPEAN REGION

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The presence of aeolian dust in the atmosphere may play an extremely important role in climatic variations. Recent studies have stressed the influence on climate forcing of mineral aerosol, while others have pointed out the impact the dust has on the alteration of gases becouse dust particles are a good surface for chemical reaction.
Several dust transport events with a high mass concentration were identified at Mt.Cimone (44 N, 10 E, 2165 m asl), a baseline mountain site in the northern Italian Apennine. The synoptic situations and the back trajectory analysis show that transports of dust occurred principally from the Sahara desert. Given its position and elevation this site is particularly suitable for direct sampling during such episodes, before they cross the European Continent. The study reveals that there is a low ozone concentration during these transport phenomena. The relation between the events of Saharan dust transport and their effects on ozone recorded at Mt. Cimone are analysed with the meteorological conditions that gave rise to the transport. Two hypotheses to explain these alteration in ozone concentration are proposed.

OZONE AND OTHER TRACE GAS MEASUREMENTS USING THE TRANS-SIBERIAN RAILROAD; THE TROIKA EXPEDITION 96

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Using a laboratory wagon traveling along the Trans-Siberian railroad, O_3, NO, NO_2, CO, CH_4, SF_6 , and black carbon aerosol have been measured, summer 1996. The expedition from Nizhiniy Novgorod (500 km east of Moscow) to Vladivostok (and back to Moscow) has shown that a wealth of boundary layer air data can be obtained without serious contamination problems. The diurnal O_3 cycle peaked generally below 50 ppbv, shows correlations with changes in $J(NO_2)$ and NO_x, and often dropped to a few ppbv at night time. Over the west Siberian lowland CO levels were generally low, reaching levels of only 110 ppbv, however, many sections were of course affected by pollution sources. In east Siberia, between about 7000 to 8000 km from Moscow, an extensive air mass with extremely high CO values of up to about 1 ppmv was crossed in both directions. Forest burning seems to be the most plausible explanation. In stark contrast, CH_4 was relatively low at about 1.85 ppmv over eastern Siberian, compared to 1.95 ppmv over much of the west Siberian lowlands. The most probable source for the excess CH_4 are the extensive and abundant wetlands in western Siberia However the occurrence of many sharp spikes suggests relatively nearby local sources, which would be anthropogenic. Isotopic analysis is in progress to try to identify the respective sources better.

VALIDATION OF A THREE-DIMENSIONAL STRATOSPHERIC CHEMISTRY TRANSPORT MODEL

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A new three-dimensional chemistry transport model is developed. The advection scheme is forced by analyzed meteorological data of the ECMWF. The resolution of the model is 3.75° latitude by 5° longitude, with 19 vertical layers, upto 10 hPa. Chemistry of the lower stratosphere is implemented, including heterogeneous reactions, both on polar stratospheric clouds and on/in liquid aerosol. The chemical continuity equations are solved using Euler Backward Iterative.
A year's run was carried out for 1995, the year in which the SESAME campaign took place. Measured profiles of both long-lived species, such as N_2O and CH_4, and chemically affected species, e.g. O_3 and ClO, are compared to the model results in order to validate the model.

MODELLING THE SEASONAL CYCLE OF OZONE IN HIGH AND MID LATITUDES AND THE IMPACT OF THE NO_X/NO_Y RATIO

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Using a two-dimensional chemical model with and without nudging with HALOE/UARS satellite data it is shown that the minimum in total ozone in summer is mostly due to catalytic destruction by NO_x under polar summer conditions in the altitude region between 20 and 30 km. With that model and with boxmodel studies along high and mid latitude summer trajectories we demonstrate also that there is evidence that the recommended rate constant for the formation of HNO_3 from NO_2+OH is too large.

ESTIMATIONS OF THE FUTURE DEVELOPMENT OF THE OZONE LAYER

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The coupled dynamic-chemical three-dimensional general circulation model ECHAM/CHEM has been used for future studies to treat problems of global climate change due to anthropogenic emissions under consideration of chemical processes in the troposphere and stratosphere, including photochemical reactions and heterogeneous reactions on sulphate aerosols and polar stratospheric cloudes. Special emphasis is given to possible changes of the ozone layer within the next decades, assuming different background conditions of relevant chemical species. In this paper results of multi-annual integrations with ECHAM/CHEM will be presented and discussed.

OBSERVATIONS OF NEAR-ZERO OZONE CONCENTRATIONS IN THE UPPER TROPOSPHERE AT MID-LATITUDES.

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Measurements by an ozonesonde launched from Aberystwyth (52.4N,-4.1E) in July 1996, into cirrus ahead of a warm frontal system, show concentrations of ozone decreasing steadily from the top of the boundary layer to the tropopause resulting in a layer ~0.5km deep exhibiting near-zero ozone concentrations at 12km. This result closely resembles profiles taken in the equatorial pacific (Kley et al.1996). Recently reported lidar measurements over Germany (Reichardt et al.1996) have also observed pronounced minima in the upper troposphere, however, such features have not previously been reported in ozonesonde data at mid-latitudes. Various mechanisms have been proposed to explain the existence of very low ozone concentrations in the troposphere, for example: heterogeneous chlorine activation on the surface of the cirrus (Borrmann et al. 1996), or by destruction in the tropics (Sander and Crutzen. 1996) and subsequent transport to higher latitudes. The processes resulting in this ozone poor layer will be illustrated using satellite images and trajectory analysis.

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TOTAL OZONE MEASUREMENTS FROM BELSK, POLAND; COMPARISON OF THE DOBSON DATA WITH THOSE FROM VERSION 7 TOMS IN 1978-1993

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Total ozone measurements taken by means of the Dobson instrument No.84 at Belsk, Poland, were compared with the total ozone data from version 7 TOMS in the period 1978-1993. The mean difference of 4573 daily ozone means as obtained from both data sources is -0.06%, the standard deviation being 3.54%. The greatest values of the differences between the TOMS and Dobson 84 data are observed in November, December and January when the Dobson ozone measurements at Belsk are less accurate because of the lowest Sun elevations. The monthly means of daily differences between the TOMS and Dobson 84 data show no statistically significant drift of the data with time. A comparison between the ozone trend estimates for Belsk using the TOMS and Dobson data in the period January 1979 through December 1992 indicate that independently of the season the trends are in very good agreement with those previously published.

A CHLORINE MONOXIDE CLIMATOLOGY FOR THE ARCTIC FROM 1991 TO 1996 WITH UARS MICROWAVE LIMB SOUNDER DATA, ECMWF PV AND TEMPERATURE ANALYSES AND NOAA/NESDIS TOTAL OZONE COLUMN ANALYSES

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At the Finnish Meteorological Institute is research carried out into ozone anomalies in the Arctic vortex. Ozone anomalies are a result of dynamical, chemical and radiative processes. The mutual significance of these processes is strongly variable during the life cyclus of the Arctic vortex. The years 1991-1996 are discussed. Regression statistics and individual cases will be shown for the simultanuous development of lower stratospheric ClO (NASA/UARS Microwave Limb Sounder retrievals), temperature, potential vorticity (ECMWF analyses) and O3 column (NOAA/TOVS infra-red retrievals). Elevated ClO volume mixing ratio's of 3.5ppbv at 46hPa are observed in filamentary areas with PV=40 at 475K. The areas with elevated ClO coincide with decreased total ozone columns downto 210DU. However, the elevated ClO mixing ratio's do not systematically coincide with temperatures below thresholds for Polar Stratospheric Cloud (PSC) formation.

THE GEOMAGNETIC FIELD AS A GLOBAL EXTERNAL SYNCHRONIZER OF BIORHYTHMS

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The Geomagnetic Field (GF) is a main geophysical synchronizer of biorhythms.There is a direct relation with the high level correlation (r=0,9) between the diurnal vector variations of the GF (Inclination, I and Declination, D) and diurnal variations of a cell membrane permeability to an ions, gases,un-and organic molecules and also physiological processes in plant, animal and human organisms. A magnetic storms change suddenly and strong the cell permeability and cause heart attack, cerebral and hypertonic crises, deaths.

To prove the validity of our results it ought to compare a daily variations of the I (in thousand parts of degree !) and the D (in minutes) with a circadien rhythms of any physiological parameters (in 24-hour scale!) at the same exact time (GMT) and datum when the studies were done. A hourly values of the I and D components of GF must be taken from nearest geophysical observatory to a location of a study. Results are published in the book: A.P.Dubrov "Geomagnetic field and life. Geomagnetobiology.", NY Plenum Press Corp. 1978, 360pp.

VARIATIONS OF TOTAL OZONE IN 1970-1995: TWO-DIMENSIONAL MODEL STUDY

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A two-dimensional model of diabatic circulation, temperature, gaseous and aerosol constituents of the troposphere and stratosphere is used to examine global variations of the ozone layer in 1970-1995.
We show that pollutions containing nitrogen, chlorine, and bromine compounds result in a decrease in total ozone. The maximum values (~ -0.25% ÷ -0.35% per year) for such variations are observed in winter in the polar latitudes of both Northern and Southern hemispheres. In this case, a season-latitude trend in total ozone is entirely due to stratospheric processes at altitudes from ~ 12 km to ~ 24 km. In the troposphere at all latitudes we recognized a positive trend (~ 0.12% ÷ 0.18% per year), wich is due to atmospheric discharges of CO and CH_4. Changes in a solar UV flux accompanying transitions of solar activity minimum to maximum result in additional changes in total ozone from ~ -0.12% per year near the equator to ~ -0.21% per year at the poles. The sink of gaseous components at the surface of aerozol particles ice, $3H_2O{\cdot}HNO_3$, and water solution of H_2SO_4 in the troposphere and lower stratosphere significantly increases the total ozone decrease only in Antarctica.

THREE-DIMENSIONAL MODELING STUDIES OF THE GLOBAL IMPACT OF AIRCRAFT EMISSIONS ON ATMOSPHERIC OZONE: SENSITIVITY TO PSC, SULFATE, AND NO_y LOADING

Richard S. Eckman and William L. Grose (NASA Langley Research Center, Mail Stop 401B, Hampton, VA 23681 USA)

The NASA Langley three-dimensional chemistry transport model (CTM) is used to examine the impact of future subsonic and supersonic aircraft emissions on ozone. Recent assessments of the affects of stratospheric aircraft on the atmosphere have emphasized the need to quantify the uncertainties in model predictions. Multiple simulations have been conducted with the Langley CTM to characterize the response of ozone to the presence of polar stratospheric clouds (PSCs), sulfate aerosols, and tropospheric NO_y from lightning. Formal assessment models have not included the impact of PSCs. We find that when PSC chemistry is enabled in the Langley model that the response of southern hemispheric ozone to a future fleet of aircraft was substantially reduced due to significant denitrification during polar winter and spring. The inclusion of chemistry occurring on sulfate aerosols also moderates the impact of aircraft NO_x emissions on ozone. The impact of an additional tropospheric source of NO_y from lightning, principally in the tropics, on aircraft perturbations will be examined.

VALIDATION EXPERIMENTS FOR NEW EXTENDED UMKEHR METHOD OF OZONE PROFILES DETERMINATION

N.F.Elansky and **O.V.Postylyakov** (Institute of Atmospheric Physics, Pyzhevsky per.3, Moscow 109017, Russia)
V.M.Dorokhov (Central Aerological Observatory, Dolgoprudny, Moscow Region 141700, Russia)
V.V.Zuev (Institute of Atmospheric Optics, Tomsk, Russia)

A new method for ozone profile retrieval, using Umkehr-similar measurement and extending its possibilities, was proposed earlier [1]. Theoretical study of extended Umkehr algorithm shows its good accuracy characteristics. To verify field accuracy of the extended Umkehr method, authors carried out correlative measurements of ozone vertical distribution using ozone sondes (Yakutsk, 62N 129E) and UV lidar (Tomsk, 57N 87E). Extended Umkehr measurements of ozone were performed by Brewer MKII instrument and spectrophotometers of the Institute of Atmospheric Optics. Results of these validation experiments are discussed. [1] N.F.Elansky , I.V.Mitin, O.V.Postylyakov. A new approach to Umkehr observations of vertical ozone distribution at ozone network. Doklagy Akademii Nayk, 347, 539-543, 1996.

TOP ACCURACY OPPORTUNITIES OF EXTENDED BREWER UMKEHR METHOD FOR OZONE P ROFILES DETERMINATION

N.F.Elansky and **O.V.Postylyakov** (Institute of Atmospheric Physics, Pyzhevsky per.3, Moscow 109017, Russia)
I.V.Mitin (Moscow State University, Vorobjevy Gory, Moscow, Russia)

Umkehr method is used for ozone profile determination at network of Brewer instruments. Because currently operated inversion algorithm was initially developed for Dobson instrument, it didn't take into account particularities of Brewer. To operate Brewer and Brewer-similar instrument with full usage of its potential, extended Umkehr method for ozone profile determination is developed. The extended Umkehr algorithm is based on the on the invariant statistical estimation method. The reduction of retrieval error in comparison with Dobson-Brewer Umkehr algorithm reaches its maximum value in the lower stratosphere. Protocol of extended Umkehr observation could be optimized to increase retrieval accuracy, what gives up to 20The retrieval and accuracy analysis results are compared for multi scattering and single scattering radiative transferee models.

LONG-TERM CHANGE OF PLANETARY WAVE TRANSPORT, A LINK TO THE LONGITUDE-DEPENDENT TOTAL OZONE TREND IN MEAN LATITUDES DURING WINTERS 1979 - 1992

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In winters (December, January, February) 1979 - 1992 deviations from the zonal mean of total ozone (TOMS) and of the 300 hPa geopotential reveal a significant decadal change, distributed in clear longitude dependent spatial structures. While during December/January the most distinct ozone trend structures are characterised by an increase (>10 DU/10yrs) above the Atlantic Ocean and Eastern Europe and a decrease (up to -30 DU/10yrs) above Central Europe, in February the region of decreasing ozone above Central Europe is replaced by the shifted Atlantic area of increasing ozone. The ozone change and its spatial structure is investigated by a 14 layer (500 to 1 hPa) linear quasi-geostrophic transport model. The stationary waves 1 to 4 explain 50 to 70 % of the observed total ozone change via their horizontal and vertical advections. The contribution of different wave classes to the horizontal and vertical advection of ozone and its vertical distribution are discussed. It can be shown that the main influence is in the height region between the tropopause and the ozone layer maximum.

VARIATIONS OF OZONE CONCENTRATION IN THE PERIODS OF FORBUSH DECREASES IN COSMIC RAYS

I.N. Fedulina (Institute of ionosphere, Kamenskoe plato, 480068 Almaty, Republic of Kazakstan)

An analysis of the ozone behavior during decreasing of galactic cosmic ray (GCR) fluxes is reported. We examined total ozone data for 1978 from 29 ozone stations located in the latitudinal range of 35° - 60° N. The data were grouped in 4 crossed latitudinal ranges and analyzed by a superimposed epoch method. The days of 7 Forbush decrease (FD) maxima observed by Moscow (55.75° N) neutron monitor were used as key days. The results show that total ozone content is decreasing almost synchronously with GCR intensity. After reduction the positive phase of ozone occurs and reaches a maximum after 9-11 days. Variations were 2 to 3% at all latitudes. For details ozone profile data from ozonesonde stations Wallops Island (37.93°N), Tateno (36.05° N), Edmonton (53.55° N) and Churchill (58.75°N) for the years 1974-1990 were analyzed. We selected 38 sets of ozone data; each of them included 3 profiles. The first was measured in the period of the FD maximum (key day); the second and the third were obtained approximately a week before a key day (quite day) and after a week respectively. The differences of first and third profiles from quite one were considered. The 20-60% ozone depletions were detected for more than 70% of FD events at the level from 100 to 200 mb. The positive changes of ozone concentration expected a week after FD were observed between 100 and 500 mb.

OZONE DEPLETION BY SULPHATE AEROSOLS AND PSCs

V. Grewe and M. Dameris (DLR, Institut für Physik der Atmosphäre, Oberpfaffenhofen, D-82230 Weßling, Germany)

Changes in ozone concentration due to different levels of stratospheric sulphate aerosol and polar stratospheric clouds (PSCs) occurence are presented using multi–annual integrations of the coupled dynamic–chemical 3 dimensional general circulation model ECHAM3.2/CHEM. Aerosols and PSCs influence the partitioning of NOY and ClY components via temperature dependent heterogeneous reactions. The interaction between the NOY and ClY katalytic ozone destruction cycles are affected in a strongly non–linear way by aerosols and PSCs. The paper especially aims at the seasonal and spartial variations of these aerosol and PSC induced changes in the partitioning of NOY and ClY and their imapact on ozone. Two situations will be discussed: An atmosphere with low values of sulphate aerosol surface, which is found several years after any significant vulcanic injection of sulphur and secondly with high values of sulphate aerosol surface, representing the situation shortly after a strong vulcanic eruption.

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THE GLOBAL IMPACT OF FUTURE SUBSONIC AND SUPERSONIC AIRCRAFT EMISSIONS ON THE ATMOSPHERIC OZONE COLUMN: A THREE-DIMENSIONAL MODEL SIMULATION

William L. Grose and Richard S. Eckman (NASA Langley Research Center, Mail Stop 401B, Hampton, VA 23681 USA)

Multi-year simulations have been conducted with an atmospheric chemical transport model (CTM). The horizontal dependence of the prognostic variables in the model is represented with a truncated series of surface spherical harmonics (T16 horizontal resolution) with vertical domain extending from the surface to approximately 60 km (24 vertical levels). The model formulation includes a comprehensive treatment of gas phase chemistry and heterogeneous chemical processes on polar stratospheric clouds and sulfate aerosols. The results demonstrate that the model produces a very credible simulation of many observed features of the circulation and distribution of constituents in the stratosphere, including the seasonal formation and subsequent decay of the Antarctic ozone hole. The results from a control simulation (one including emissions from an all-subsonic aircraft fleet in 2015) will be compared with results from a second simulation that includes emissions from a mixed fleet of subsonic and supersonic aircraft and a route structure assumed for the year 2015. The aircraft source emissions are taken from a compilation developed under the NASA Atmospheric Effects of Aviation Program (AEAP). Results to be presented will focus on the seasonal and latitudinalperturbations in the column ozone resulting from the aircraft emissions. Additional comparisons will be made with calculations produced by current two-dimensional assessment models to identify any significant differences arising as a result of 3-D versus 2-D dynamics in the models.

A NEW STAR-POINTING SPECTROMETER FOR MEASUREMENTS OF STRATOSPHERIC CONSTITUENTS DURING POLAR NIGHT ON SVALBARD

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Kjersti Karlsen, Geir Bråthen (NILU, P.O.Box 100, N-2007 Kjeller)

A new star-pointing spectrometer consisting of a telescope and a spectrometer coupled by an optical fiber has been set up at the Auroral Station in Adventdalen near Longyearbyen, 78.1°N, 15.4°E, on Svalbard. Measurements of ozone and other stratospheric constituents which are involved in ozone depletion chemistry are mostly measured after the sun returns to polar latitudes approximately in early march. During the polar night when conditions for ozone loss are initiated, the only continuous natural light sources are provided by stars or planets. The brightest ones can be used for UV-VIS spectroscopy if enough of their light can be collected by the use of a telescope. A highly sensitive CCD camera is used with the spectrometer for detection, since light intensities from stars are poor. The coupling between the spectrometer and the telescope is maintained by an optical fiber bundle where some fibers are used for the star and some for background light from aurora. With this instrument we are able to observe an array of stratospheric constituents, i.e. ozone, OClO, NO_2, and NO_3, which are essential for the understanding of the chemical processes that take place in the stratosphere during polar night. The instrumental set-up and the first measurements from winter 1996/97 will be shown.

THE CORRELATION DECAY TIME OF WIND TURBULENCE OVER THE OPEN OCEAN

Katja Henjes (James Rennell Division for Ocean Circulation, Southampton Oceanography Centre, Southampton SO14 3ZH, England, UK)

Correlations in turbulent wind speed data from the open ocean are studied. Data was obtained for wind speeds between $0.3 m/s$ and $27 m/s$; the stability range was $z/L = -2.0 \sim +0.5$. The 3 wind speed components were measured at a $21 Hz$ sampling rate with a ship-borne sonic anemometer.

The correlations are calculated via Fourier transforms of the spectral coefficients, which are computed from FTs of the measured wind speed components. It is found that all observable correlations decay within a correlation time τ of only a few seconds. This is in good agreement with the expectation to find a universal inertial range on distances small compared to the scale of vertical inhomogeneity only. However, the decay time is also possibly limited by displacements of the anemometer due to the pitch of the ship.

Inertial range spectra can be efficiently calculated using τ long runs. Nothing is gained by using longer data sections, they simply include more random noise. Some consequences for the measurement of momentum fluxes will be discussed.

OZONE DIURNAL VARIATIONS OBSERVED BY UARS AND THEIR MODEL SIMULATION

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J. Austin (UK Meteorological Office London Rd Bracknell Berks RG12 2SZ, UK)

Several years' ozone measurements from the Microwave Limb Sounder are analysed using a 2-D Fourier series in day of year and time of day. Data are investigated between 0.46 and 21 mbar and between 28°N and 28°S. Ozone is found to be a maximum in the afternoon at 3 mbar and a minimum in the afternoon at 1 mbar and above with a narrow transition zone of reduced diurnal variation in between. Comparisons are made with results from a photochemical box model run for 28°N at spring equinox and near the solstices. In the middle stratosphere the model results are in poor agreement with the observations because of the influence of stratospheric dynamics. In the upper stratosphere, expressed in terms of the relative deviation from the midnight value, the model shows excellent agreement with the observations and in particular correctly simulates ozone in the transition zone between 3 and 1 mbar. Model sensitivity studies are performed to determine the effects of major reaction rate changes and simplified tidal effects.

QUANTIFICATION OF VORTEX LEAKAGE

B.M. Knudsen (Danish Meteorological Institute, Lyngbyvej 100, DK-2100 Copenhagen, Denmark)

Contour advection and reverse domain-filling trajectory (RDF) techniques have successfully modelled filaments of vortex air peeled of the arctic vortex in a qualitative sense. Observed filaments have shown up in the calculations, but not necessarily at the right position or with the right size. Using high resolution RDF calculations the ability to model the amount of vortex leakage will be investigated. A large number of satellite and aircraft observations of filaments will be used for this purpose. The quantification of vortex leakage is important for assessing the causes of the observed mid-latitude ozone depletion, since the transport of air primed for ozone depletion or air already depleted in ozone has a substantial influence on mid-latitude ozone.

POSSIBLE MECHANISM OF SPRING OZONE DECREATION OVER SOUTH POLE

A. Krivolutsky(Central Aerological Observ. Pervomayskaya 3,141700 Dolgoprudny,Moscow Region, Russia)

Special study on base of 1-D photochemical model and numerical analysis for non-linear behaviour of oxygen minor atmospheric components was used to investigate the reaction of ozone over S.pole in presence of a very low pressure after winter. Such effect leads to reduced production of ozone and the results of model calculations has shown 50% ozone decreation in Stratosphere.The results has shown also that we can't simulate real rapid ozone decreasing if "chemical families" tecknique is used and we should solve non-linear system using little step of integration in accordance to real times of chemical relaxation.

A CLIMATOLOGY OF OZONE MINI-HOLES OVER THE NORTHERN HEMISPHERE

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A climatology of occurrences of the ozone mini-hole phenomenon over mid- and high-latitudes of the northern hemisphere is constructed, based on daily Nimbus-7 TOMS total ozone measurements for the period of November 1978 to April 1993. An ozone mini-hole is a synoptic-scale area of strongly depleted column total ozone amounts, which undergoes a cycle of growth and decay, in direct association with tropospheric weather systems. A method for defining a mini-hole is introduced and used to build up a catalogue of mini-hole events, each being recorded as a daily set of tracks and minimum ozone values. The resulting climatology is analysed in terms of geographical and seasonal variations of mini-hole frequency and intensity. Possible statistical trends over the 15-year period are also assessed. Ozone mini-holes are found to be primarily a winter half-year phenomenon, are far more frequent over the North Atlantic / European sector than the North Pacific / North American sector (a major finding of the study) and exhibit a slight local orographic enhancement, being more frequent over large mountain chains. The connection to synoptic weather systems is illustrated by correlating mini-hole occurrence with large-scale weather circulation type ("Grosswetterlagen") statistics over Europe. Ozone mini-holes occur in regions of strong upper tropospheric ridging, usually between the warm sector of a cyclone and a blocking surface anticyclone.

STATISTICAL STUDY OF COSMIC RAYS INFLUENCE ON TOTAL OZONE BY REGRESSION METHOD

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N.Perejaslova, M. Nazarova(Institute of Applied Geophysics, Moscow, Russia)
G. Bazilevskaya (Lebedev Physical Institute of Russian Acad. of Science, Moscow, Russia)

The results of solar proton fluxes mesurements by russian satellite system "Meteor" since 1969 to 1994 for different intervals of energy were used jointly with total ozone data sets (ground based observation for several points in Russia) for regression analysis. Mean - year values of total proton numbers and total ozone were used for calculations. Also the results of charged particles intensity (due to galactic cosmic rays influence) at Murmansk,Moscow and Alma-Ata were used for analysis. Long-term variations of total ozone induced by cosmic rays has been revealed.

COMPARISON OF PEROXY RADICALS CONCENTRATIONS AND OZONE GENERATION RATE FOR URBAN AND RURAL REGIONS OF RUSSIA

Genady I. Kuznetsov, Oksana A. Terekhova
Moscow State University, Department of Atmospheric Physics

Several long-term series of measurements of the surface concentration ozone, nitrogen oxides and other minor species were carried out in different urban and rural regions of Russia. Some meteorological parameters and radiative characteristics were also measured. On the base of these data concentrations of peroxy radicals and ozone generation rate were calculated. It was shown that calculated parameters are strongly depend on the atmosphere condition when concentrations of O_3, NO and NO_2 and radiation flux were measured.

To estimate the rate of ozone generation and concentration of peroxy radical the deviation from photochemical equilibrium of $O_3 - NO_x$ system was used. These quantities complex depend on clouds, sun zenith angle and atmospheric pollution. Comparison shows that considered process are much stronger in rural region then in urban.

THE EFFECT OF SMALL-SCALE INHOMOGENEITIES ON OZONE DEPLETION IN THE ARCTIC.

B. Legras and S. Edouard (Laboratoire de Météorologie Dynamique du CNRS, 24 rue Lhomond, 75231 Paris Cedex 05, France)

The chemical processes involved in the polar stratospheric ozone depletion are fairly well understood. But the effect of small scale stirring and mixing of the chewmical species involved can be misrepresented in 3D chemical transport models because of their coarse re solution. Because of the non-linearities in the chemical rate laws, especially those involving chlorine in the main catalytic cycle, these effects can be important — particularly in the Arctic. Here we use a very high-resolution horizontal transport model with a simplified ozone chemistry to show that ozone depletion is sensitive to small-scale inhomogeneities (Edouard et al., Nature, 5 Dec 1996). Under the conditions of winter 1994-1995, the effect is large enough to account for the observed discrepancies, of about 40%, between modelled and observed ozone depletion in the Arctic environment (Goutail et al., J. Atmos. Chem., 1997, to appear). Moreover our model agrees with maximum local depletion (of the order of 60% estimated from ozone soundings matched with trajectories (M. Rex, 1997). We hope to present new calculations for winter 1995-1996 during which the average depletion has been as important as in 1994-1995.

ON THE PROBLEM OF THE SPACE PARAMETERS INFLUENCE ON THE ATMOSPHERIC OZONE VARIATIONS

L.N.Makarova and A.V.Shirochkov (Arctic and Antarctic Res.Institute,Saint-Petersburg, 199397, Russia)

The data of the baloon measurements of the total ozone content at antarctic station Mirny during spring-summer of 1989 (25 cases) were compared with the correspondent positions of the Earth magnetosphere magnetopause obtained from the experimental and model data. High correlation (r=0,91) was found between the magnetopause position and such parameters as the height of maximum ozone density and the temperature at this height. Correlation between the maximum ozone density itself and the magnetopause position is a bit worse but it is rather reliable (correlation coefficient is 0.60). The results are explained in the framework of the modified conception of the global electric circuit where its external element is magnetopause which changes its position under influence of the solar wind dynamic pressure.

SUBSIDENCE AS TRACER FOR SHEARED-OFF VORTEX FILAMENTS: RETRIEVAL METHODS AND APPLICATIONS

Arndt Meier (IRF, Swedish Institute of Space Physics, Box 812, S-98128 Kiruna)

It is still an open question how much of the negative stratospheric ozone trend in mid-latitudes might be caused by transport of chemically processed or preconditioned air masses from inside the polar vortex. Air masses inside the vortex cool down during the winter period and the profiles of trace gases get crunched in the lower atmosphere, which is termed as subsidence. By determination of the amount of subsidence in the air masses probed, an identification of its origin is possible.

Here the technique is presented how the amount of subsidence is retrieved from ground-based FT-IR solar and lunar absorption spectra by combining line-shape and total column information in a global minimum search on a set of spectra recorded under different zenith angles and by analysis of a set of different dynamical tracers with different VMR profiles and different temperature sensitivity in their optical properties. Besides the determination of the subsidence itself, its use in the correction of the *a priori* VMR profiles assumed in the retrieval improves the accuracy of the reported total column amounts significantly for the 30 different trace species measured.

The demonstration of the method is given with data recorded on Spitzbergen (79°N, 12°E) in March 1995, while examples of air filaments sheared off the vortex are expected to be given for this winter 96/97 for the observation site of Kiruna (68°N, 20°E).

OZONE FORMATION: NEW PUZZLES FROM REGULAR ISOTOPIC OBSERVATIONS

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Experimental data from *in-situ*, laboratory, and optical remote sensing techniques from ground, balloon and space based platforms have well affirmed a strong isotopic effect in ozone in the stratosphere and troposphere as well as in laboratory studies. However, the theoretical understanding of ozone formation is still incomplete and fails to explain the observed isotopic signals.

The overwhelming amount of ozone has its sources in molecular oxygen, which is known to have a content of 2 permil of heavy ^{18}O. Compared to this figure, we observe a relative enrichment of 11 % in symmetric $^{16}O^{18}O^{16}O$ and 15 % in asymmetric $^{16}O^{16}O^{18}O$ in sunlit airmasses and a significantly lower enrichment during polar night. At the end of polar night even a full diurnal cycle is observed on a particular day, which is phase shifted for the two species studied. We will extend our present analysis of ground-based FTIR spectra from Kiruna (68°N, 20°E) and Ny-Ålesund (79°N, 12°E) and correlate it to different parameters from trajectory analysis. Possibly we might be able to derive a recombination rate for ozone.

TRENDS IN OZONE LAMINAE - GEOGRAPHIC DEPENDENCE

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Our previous analyses showed that there was a strong trend in positive laminae in ozone profiles at higher middle latitudes (~50° N). This trend is expressed best for the overall ozone content in laminae per profile, where it attains a decrease by about 50% per 20-25 years. In this paper, we deal with trends in ozone laminae at higher (Resolute) as well as lower (Tateno) latitudes. The trends seem to be comparable at all latitudes studied. On the other hand, their "ozone" origin is different - in Europe, the trend is essentially caused by a decrease of the number of laminae, while in Canada the decreasing size of laminae prevails. At least part of these changes is attributable to changes in circulation. The above results concern laminae of size >40 nbar. We present also some results for laminae >30 or 20 nbar.

ON THE STRATOSPHERIC STRUCTURE OF THE ZONALLY ASYMMETRIC INTRASEASONAL AND INTERANNUAL OZONE VARIABILITY IN BOREAL WINTERS

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An extended SVD analysis (singular value decomposition) was used in combination with a linear transport model to examine the stratospheric structure of the zonally asymmetric intraseasonal and interannual ozone variability in northern hemispheric winters. The data sets are based on detrended monthly mean values of column integrated ozone (TOMS, version 6) and three-dimensional geopotential fields (14 levels between 700 and 2 hPa; NMC-data) from 1979 - 1992. The first four modes of SVD analysis explain more than 70 % of the covariance for the intraseasonal variability and more than 80 % of that for the interannual variability. A clear wave-1 pattern for modes 1 and 2 and a wave-2 pattern for modes 3 and 4 are found in the stratosphere, which show different but generally westward tilted phases. The results of linear transport model calculations for ozone will be shown and discussed.

THE OZONE FULL CONTENT VARIATION IN PERMAFROST REGION

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The spatial distribution of ozone over the territory of the USSR for the period 1972–1979 is studied. It is shown that for cold seasons the permafrost boundary coincides with the area of higher ozone content and with the area of higher atmospheric transparency. For non-permafrost areas the ozone content increases towards the higher latitudes, in permafrost region the dependence of ozone content on latitude is very weak. The explanation of these phenomena is given.

TOTAL OZONE DISTRIBUTION OVER POLAND FROM VERSION 7 TOMS DATA (1978-1993)

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The total ozone distribution (TOD) over Poland is inferred from the new Version 7 TOMS data. The data used consist of the monthly means of total ozone (TO) in the period October 1978 through April 1993 for 80 grid cells of 1° by 1.25° (latitude by longitude) covering the area of Poland. The seasonal variations of TOD have been found, i.e., rougly speaking, the TO isolines are along the meridians in winter but perpendicular to the meridians in the early spring (March, April); in November it seems that the isolines are inclined to the meridians. It appears that there are only small differences between the long-term (1978-1993) TO monthly means over the different parts of the analyzed region. In extreme cases, it is possible that in a selected month of the period 1978-1993, especially during winter, the TO monthly means somewhere in the analyzed region could differ by more than 5% of the TO calculated from the TOMS overpasess over Belsk in this month. Several statistical characteristics are examined to find long-term evolution of the TOD over Poland. The seasonal and year-round trends from the TOMS overpasses over Belsk are almost equal to those in the TO averaged over all grid cells in the analyzed region. For all grid cells, almost similar drift of TO towards lower values can be inferred. However, this drift seems to be accompanied by slightly larger TO depletion along the west border relative to that along the east border of the considered region.

5 YEARS OF OZONESONDING AT S. PIETRO CAPOFIUME STATION (ITALY)

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I. Kostadinov, Bulgarian Academy of Science - STIL

A monitoring activity of stratospheric ozone monitoring started in summer 1991 at S. Pietro Capofiume Station, in the Southern Po Valley, near Bologna. Weekly ozone sonding are performed via ECC ozone sensor toghether with meteorological radiosonde. in order to measure the vertical profile of ozone concentration, temperature, relative humidity, wind speed and direction up to 35 Km. For each sounding the ozone column is calculated from the vertical concentration profile and compared with simultaneus Dobson measurement. in order to check the quality of the ozone sonding. Dobson measurements are performed in the AD wavelenght pair, 3 to 5 time a day, depending on the sesaon, with Dobson #66, which was calibrated against NOAA secondary standard #65 in May 1993. The 5 years data recorded at S. Pietro Capofiume station is presented and discussed, toghether with satellite data.

OZONE AND NITROGEN DIOXIDE MEASUREMENT BY MEANS OF AN AUTOMATIC DOAS STATION AT TERRA NOVA BAY (ANTARCTICA)

F. Ravegnani, G. Giovanelli, G. Trivellone , CNR - FISBAT Institute

A. Antonelli, P. Agostini, ENEA - Brasimone

I. Kostadinov, Bulgarian Academy of Science - STIL

A Differential Optical Absorption Spectrometer (DOAS) was developed at the FISBAT Institute for atmospheric trace gases (ozone, NO2, OClO and BrO) measurements during the last few years. After several tests both in laboratory and in Antarctic region, the spectrometer, called GASCOD, was modified in collaboration with ENEA for unattended and automatic measurement in extreme enviroment. The instruments was installed in December 1995 in the Antactic Italian Station at Terra Nova Bay. The aim of this research is the study of denitrification processes during the formation of the so-called ozone hole over antarctic region. The preliminary data for the first year of measurement are presented and discussed.

THE STRATOSPHERE OVER DUMONT D'URVILLE, ANTARCTICA, IN WINTER 1992

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This analysis presents the temporal evolution of stratospheric constituents above the station of Dumont d'Urville in Antarctica from mid-August to mid-September 1992. Data sets include temperature, H2O, ClO, O3, NO2, ClONO2, HNO3 and CH4 mixing ratios and aerosol extinction coefficients at 46, 21 and 10 hPa given by the Microwave Limb Sounder and the Cryogenic Limb Array Etalon Spectrometer instruments aboard the Upper Atmosphere Research Satellite. Aerosol scattering ratios together with integrated O3 and NO2 amounts are given by a Lidar and a SAOZ instrument located at the station, respectively. Columnar O3 is also provided by the Total Ozone Mapping System instrument, completed with potential vorticity from the UK Meteorological Office assimilated data set. The study clearly emphasizes the correlation between the presence of the station inside the vortex and the activation of chlorine in the lower stratosphere (46 and 21 hPa). Evolution of integrated O3 and NO2 amounts together with temperature, O3 and H2O mixing ratios in the middle stratosphere (10 hPa) are strongly correlated to the position of the vortex with respect to the station. Others effects, such as rehydratation of the middle stratosphere inside the vortex, are also observed. Evidence of the presence of polar stratospheric clouds in the lower stratosphere can be deduced from available CLAES and Lidar data during the five-day period 25-29 August 1992.

DETECTING THE IMPACT OF AIRCRAFT INDUCED OZONE CHANGES IN 3D CLIMATE SIMULATIONS

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Aircraft induced NO_x emissions have been shown to provide a significant increase to the tropospheric ozone concentration. This leads to an additional radiative forcing of the climate system and suggests the possibility of a significant climate impact. Comprehensive 3D climate models have to be used, if the net climate impact (including feedbacks) is to be estimated. As the impact can be expected to be rather small (compared to, for example, CO_2 doubling studies), the detection of the 3D structure of the response and its statistical significance with respect to natural climate variability exhibits a non–trivial problem.

To account for this, we have conducted a hierarchy of GCM experiments, using model configurations with prescribed sea surface temperature as well as with an interactive mixed-layer ocean. The temperature response to the prescribed ozone increases (taken from aircraft sensitivity studies with CTMs) will be shown to be statistically significant, if a sophisticated signal detection strategy is applied. In the northern hemisphere, the structure of the signal is rather similar to that simulated in greenhouse warming studies. Hence, the effect of aircraft induced ozone on the atmosphere acts to increase the "global warming" arising from the accumulation of long–lived greenhouse gases in the atmosphere.

AN OZONE CLIMATOLOGY (1986-95) OF THE HIGH-ALPINE SITE AT JUNGFRAUJOCH (46°33' N / 07°59' E / 3,580 M ASL) IN SWITZERLAND

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Diurnal and seasonal ozone cycles based on half-hourly ozone means from 1986 to 1995 are presented. Evidence is provided that Jungfraujoch - in the winter - is clearly situated in the free troposphere. A spring ozone maximum is displayed in association with northwesterly winds. This features, which is common to remote / clean-air sites in the mid-latitudes on the northern hemisphere, has for long been explained in terms of stratospheric ozone intrusions. It is demonstrated, however, that at least part of the spring ozone maximum at Jungfraujoch may be due to tropospheric photochemistry. Ozone concentrations in the extended summer (April-September) season are higher with southeasterly winds than with northwesterly winds; this is due to transport of chemically processed air to the Jungfraujoch.

OZONE HOLES IN AN ATMOSPHERE WITH INCREASING CO2

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A coupled chemical/radiative/dynamical GCM is used to investigate the atmospheric response to increasing emissions of carbon dioxide. The model consists of a parameterized treatment of stratospheric chemistry included on-line in the GISS GCM, which contains a full treatment of radiation and dynamics from the solution of the primitive equations. Chemistry includes chlorine activation by heterogeneous reactions on PSCs, whose formation is temperature dependent. We have simulated the ozone response to increasing CO2 in both equilibrium and transient experiments. Ozone changes feedback on both the radiation and dynamics in this interactive model. Our experiments have indicated that the mid-latitude photochemical response of stratospheric ozone to increasing CO2 is highly dependent on the tropospheric temperature response and changes in residual circulation. In the polar regions, equilibrium experiments show that CO2 induced cooling of the lower stratosphere leads to significant increases in the vertical, horizontal, and temporal extent of the Antarctic ozone hole at large chlorine levels. This cooling, combined with a reduction in the frequency of sudden warmings, also dramatically increases ozone losses in the Arctic. Our transient experiments contain projected trends in both carbon dioxide and chlorine based on IPCC growth scenarios. The development of the Antarctic ozone hole as well as a significant 'hole' that forms in the Arctic under the more realistic transient scenarios is shown. Losses peak during 2010-2020 in our model for CO2 emissions following the 'business-as-usual' scenario, and chlorine loading following the Copenhagen amendments to the Montreal Protocol.

ON THE EFFECT OF JOINT INFLUENCE OF 11-YEAR SUNSPOT CYCLE AND QBO ON INTERANNUAL WINTER-TIME VARIATIONS OF OZONE OVER NORTH-EASTERN EUROPE.

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On the basis of monthly mean total ozone data for the period of 1973-1995 the analysis of possible connection between variations of ozone over North-Eastern Europe (reevaluated data on 5 Russian stations: St.-Petersburg, Moscow, Murmansk, Pechora and Arkchangelsk are used) in months from November till March and January means of 10,7-cm solar flux is conducted. For the analysis the all data were grouped according to easterly (E) and westerly (W) phases of QBO. On first step of the investigation the data for winters with influence of eruptions of El-Chichon and Mt.Pinatubo (1982/83, 83/84, 91/92, 92/93) as well as linear trends were excepted from initial ozone time-series. From these filtered time-series the monthly ozone anomalies were calculated (only anomalies which exceed standard deviation were taken into account). It was turned out, that in February and March the negative ozone anomalies during E and W phases correspond to solar maximums and minimums respectively, and vice versa for positive anomalies. There were 7 cases in February and 5 cases in March which were in agreement with this dependence. There was only one exception from it (in March). On second step of research a linear correlations between ozone and solar activity separately for winters with E and W phases of QBO were calculated. It was found that during W phase there are significant positive correlations in February and March: r=0,52 (February) and r=0,56 (March). On the contrary, during E phase there are significant negative correlations in these months: r=-0,86 (February) and r=-0,59 (March). So, in the paper the results which clearly show that interannual ozone variations over Northern Europe in February and March may be mainly caused by joint influence of QBO and sunspot cycle, will be published.

HOMOGENEITY ANALYSIS OF THE SURFACE OZONE RECORD (1986-1995) AT JUNGFRAUJOCH (3,580 m asl) IN SWITZERLAND

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Ozone data recorded continuously at the international high-alpine research site at Jungfraujoch in the Swiss Alps have been tested for the existence of potential inhomogeneities. Three different tests were used and applied to deseasonalized monthly ozone means (absolute homogeneity test) for the periods 1986-1995 and 1988-1995 as well as to formulated times series extracted by the difference of Jungfraujoch ozone monthly means from the corresponding Zugspitze ozone monthly means for the periods 1986-1994 and 1988-1994 (relative homogeneity test). The tests revealed trend and shift discontinuities. With the trend discontinuity we do not know how much is attributed to the unremoved long term natural and climatic variability, and how much to an artificial reason. Analysis of other atmospheric variables such as wind speed, temperature, global radiation and pressure show trend discontinuities very close in time with the trend discontinuity of the ozone data. This finding provides evidence that part of the trend discontinuity is natural. The observed shift discontinuity may, however, be attributed to a change in the instrument. Further analysis is necessary to correctly adjust the Jungfraujoch ozone record.

COMPARISON OF VARIOUS COLUMN OZONE FORECAST PROCEDURES IN AUSTRIA

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In this work we study the accuracy of different column ozone forecasting procedures. We use for these investigations the measurements of column ozone which have been performed at Sonnblick observatory since Summer 1993. This study is performed in two steps: in a first step we study the calculation routines used within various existing forecast methods and compare the calculations performed with those with the data of Sonnblick observatory for the period 1993 to 1996. For these first comparisons only measured - and not ECMWF forecasted data - temperature, geopotential and vorticity fields are used. In a second step we look at the accuracy of the same calculations performed with ECMWF forecasted data.
At last a forecast routine for Austria is presented.

DECREASE OF TOTAL OZONE AT LOW LATITUDES IN THE SOUTHERN HEMISPHERE BY A COMBINATION OF ADIABATIC AND DIABATIC PROCESSES

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Detailed analysis of the edge of the Antarctic polar vortex shows that it must be considered as a region of finite latitudinal extent rather than as an infinitely narrow boundary. A refined definition of the external boundary of the vortex edge allows the study of events where the edge becomes strongly dilata ted towards lower, even subtropical, latitudes. Such events have been observed by Argentinian subtropical UV measurement stations and can also be found in TOMS total ozone observations. The dilatation of the vortex edge begins as an adiabatic deformation of isentropic surfaces, but eventually leads to irreversible diabatic mixing at low latitudes, where the horizontal gradients in Ertel potential vorticity are small.
The dilatation of the vortex edge in the studied events is demonstrated to be due to the action of a planetary wave with wave number one. Planetary waves do not only affect the low latitude ozone by causing vortex edge dilatation events, but may also by themselves lower the ozone column, as they will adiabatically decrease the isentropic density of the ozone layer in some regions (and increase it in other regions).

A SPECTROSCOPIC DATABASE FOR SATELLITE REMOTE SENSING OF CHLOROFLUOROCARBONS

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Since chlorofluorocarbons (CFCs) have been proven to be effective in destroying atmospheric ozone, there has been an intensive effort to monitor the atmospheric concentrations of these compounds using satellite remote sensing. Atmospheric spectroscopic detection of the CFCs requires accurate laboratory data on the absorption cross-sections. We present here the extensive data that we have obtained in our laboratory on the absorption cross-sections in the important thermal infrared bands of CFC-11 ($CFCl_3$), CFC-12 (CF_2Cl_2), CFC-14 (CF_4), HCFC-22 ($CHClF_2$), and CCl_4. These data obtained at temperature-pressure combinations representing various model atmospheres are useful in the interpretation of data obtained in solar-occulatation type satellite remote sensing missions.

NONZONAL HEATING RATES IN THE STRATOSPHERE CAUSED BY LARGE-SCALE TOTAL OZONE INHOMOGENIETIES.

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Resent studies of stratospheric dynamics have shown the possible importance of nonzonal ozone heating caused by absorption of solar radiation on large scale inhomogenities of total ozone for generation of planetary transient waves and atmospheric tides. Harmonic analysis of TOMS (Ver.7) global ozone data from 1979 to 1994 was applied in order to explore the spatial structure and temporal variation of ozone nonzonalities. The magnitudes of total ozone first harmonics reached of about 30-100DU in latitudial belt -60°-70°S.Hem-re and for September-October periods. The parameterization of ozone heating rates for Huggins, Chappius and Hartley spectral bands suggested by Strobel(1978) and regression method Bojkov (1969) which permits to restore vertical ozone distribution using total ozone values were applied for investigation spatial structure of nonzonal part of ozone heating. The results of calculation of nonzonal ozone heating for September-October period caused by existing in the Southern Hemisphere ozone large-scale nonzonality revealed the most important role of Huggins band for 40-45km levels and Chappius band for 20-25km. The corresponding magnitudes of first harmonics of nonzonal heating reached 1 deg./K for Huggins and 0.1 deg./K for Chappius band.

Stratospheric Arctic winter and spring profiles of N_2O_5, NO_2, and HNO_3, measured by MIPAS-B

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Vertical profiles of HNO_3, N_2O_5, and NO_2 inside the arctic vortex were retrieved from nighttime infrared limb emission spectra measured by the Michelson Interferometer for Passive Atmospheric Sounding, Balloonborne version (MIPAS-B) instrument from Kiruna (Sweden, 68°N) on February, 11 and March 21, 1995, as part of the Second European Stratospheric Arctic and Midlatitude Experiment (SESAME). Spectra were analyzed by a multiparameter nonlinear least squares fitting procedure in combination with an onion-peeling retrieval algorithm. The HNO_3, N_2O_5, and NO_2 results were derived from spectral features within the bands near 11.4 μm, 12.5 μm, and 6.2 μm, respectively. From the spectra of the February flight, peak mixing ratios of 10.2 ppb HNO_3 at 28.2 hPa, 1.1 ppb N_2O_5 at 17.1 hPa, and 2.8 ppb NO_2 at 12.0 hPa pressure altitude were inferred. Results of both flights are compared to each other and interpreted in the context of ozone-relevant chemistry.

OA28/ST23 Heterogeneous processes of ozone destruction in the stratosphere and troposphere

Convener: Wahner, A.
Co-Convener: Rossi, M.J.

POLAR STRATOSPHERIC CLOUDS CLIMATOLOGY BASED ON LIDAR OBSERVATIONS AT MCMURDO STATION (78S,167E) FROM 1993

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Observations of Antarctic polar stratospheric clouds (PSCs) by ground- based LIDAR were carried out at McMurdo Station (78S, 167E) every year during the polar winter starting in 1993. The probability of PSCs occurence above the station has been estimated and, during the typical PSC season extending from early June to late September, values higher than 60% at about 25 Km of altitude were found during July. Evidence of HNO3 and H2O irreversible losses in the stratosphere due to PSC particles sedimentation during July was inferred from the pattern that PSC formation probabilities drop markely in the 15 to 25 Km region by early August, altought temperatures remain low enough in that region until mid-September. Occurences of different types of PSCs during the year were examined in terms of temperature formation and Ertel potential vorticity.

LABORATORY INVESTIGATION ON THE HETEROGENEOUS NO_X CHEMISTRY ON TROPOSPHERIC AEROSOLS

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Heterogeneous interactions on aerosol particles strongly influence the oxidizing capacity of the troposphere either by removing photo-oxidants from the gas phase or by promoting their formation by surface chemical processes. In this laboratory investigation we measured the sticking coefficients of NO_2 on model aerosols, i.e. carbonaceous particles and salt aerosols (NaCl, $NaNO_3$, NH_4SO_4). We used an in situ experimental approach, where the NO_2 was reacted with the aerosol in a flow tube reactor under controlled temperature and humidity conditions and at low NO_2 concentrations, both in presence and absence of ozone. The sensitivity required for this kind of experiments was achieved by using the radioactive tracer ^{13}N with a half-life of 10 min. Gas phase products and particle bound species were trapped in a series of selective denuders and a particle filter, respectively, to each of which a detector was attached measuring the activity from the decay of ^{13}N. Where appropriate, a chemiluminescence detector was used to measure NO_2 concentrations in the ppt range. The results obtained with this in situ approach are compared to recent results obtained with bulk materials, and the implications of the investigated reactions for atmospheric chemistry are discussed with respect to the removal of NO_2 from the gas phase and the modification of the aerosol surface.

NEW DEVELOPMENTS FOR THE DETERMINATION OF THE OXIDATION CAPACITY OF THE ATMOSPHERE

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Organic acids and carbonyl compounds are the first stable intermediates in the oxidation of hydrocarbons. The strategy of our work is to use these compounds as sensors for the determination of the oxidation capacity of the atmosphere. The concentration ratio and the time dependency between specific (e.g. homologues) pairs of aldehydes and carboxylic acids enable a valuable insight into the present status of photochemistry in the sampled air mass. Therefore, diurnal profiles with short time resolution (< 1 h) in conjunction with the low mixing ratios (pptv-ppbv range) require the development of new analytical methods. Additional information on chemical reactions of organic compounds in the atmosphere can be obtained by collecting size classified raindrops during precipitation. Using conventional sampling methods of aerosol particles the determination of volatile organic compounds (VOC) is not possible without discrimination due to the sampling procedure. A new method is presented to measure the mean aerosol particle size of VOCs in the atmosphere without discrimination effects by sampling size classified raindrops and analysing them for their chemical content. For the investigation of the chemistry in clouds it is necessary to know more details concerning the formation of clouddroplets. A new sampling method was developed for the determination of the chemical content of single cloud- and fogdroplets.

DUAL WAVELENGTH RAMAN LIDAR OBSERVATIONS OF TROPICAL CIRRUS CLOUDS DURING ALBATROSS CAMPAIGN

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First results from lidar observations of tropical cirrus clouds above the Atlantic ocean during the ALBATROSS campaign (Atmospheric chemistry and lidar studies above the Atlantic ocean related to ozone and other trace gases in the tropo- and stratosphere) in October-November 1996 are presented. The measurements were performed aboard the German research vessel POLARSTERN between 35°N and 45°S. In the tropics cirrus clouds were frequently observed in the altitude range 12 - 16 km. Between 23.5°N and 23.5°S in 44% of the observations maximum volume depolarizations exceeded 0.1; in the subtropics (23.5° - 30°S and 23.5° - 30°N) this percentage was only 11%. Often several distinct layers could be distinguished within the cirrus cloud where the highest layers were reaching tropopause altitude. Based on the ratio of aerosol backscatter coefficients at wavelengths of 355 and 532 nm an estimate of the cirrus particle sizes is derived within the framework of Mie scattering theory. As Mie theory is based on the assumption of spherical particles the analysis is applied to measurements with aerosol depolarization less than 0.1 only. We find that the dependence of the ice water content (IWC) on temperature T can be parameterized by the linear fit $IWC = \exp(-32.35 + 0.114\ K^{-1}\ T)\ g/m^3$.

REDISTRIBUTION OF CHEMICAL SPECIES BY ICE-PHASE MICROPHYSICAL PROCESSES IN A SUMMER CUMULONIMBUS CLOUD.

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Until now, ice-phase-related microphysics has been poorly addressed in studies concerning interactions between chemistry and heterogeneous cloud processes. However, it is well known that ice crystals can efficiently incorporate aerosols and chemical products, particularly during the riming processes. Hence, it is worthy to try to assess impact of ice-phase processes compared to aqueous-phase processes.

In the framework of a 2D convection model, using Stephen's parameterization for ice phase microphysical processes, uptake of chemical species such as H_2O_2, and SO_2 are analyzed, while gas phase and aqueous phase chemical reactions are taken into account with the mean of a fully coupled chemical module describing photochemistry of ozone precursors. Consequences on the whole chemical system and evaluation of relative contributions of ice-phase-related processes are studied.

INFRARED SPECTROSCOPIC INVESTIGATIONS OF REACTIONS ON SULFURIC ACID AEROSOL MIMICS.

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A new apparatus for investigations of sulfuric acid films at low temperatures has been developed. The sulfuric acid films are produced via the reaction of SO_3 with water on a silicon substrate. This substrate is placed in a cryostat under an IR-microscope. The temperature regulation is achieved by a stream of cold nitrogen gas and electric heating of the cryostat. The sulfuric acid films, their concentrations and their temperature dependence are characterized by RAIR and transmission-IR-spectra. The gas phase over the sulfuric acid films is monitored by a quadrupole mass spectrometer. Stratospheric sulfuric acid concentrations can be accomblished by maintaining a constant water vapor pressure in the cell. The sulfuric acid films were prepared and exposed to the sink gases HCl or HNO_3. In addition we codeposited SO_3/H_2O and HNO_3 or HCl at low temperatures (130 K, no reaction of SO_3 with H_2O) and heated the resulting film to stratospheric temperatures. During this procedure, the SO_3 reacted quantitatively with the excess water to H_2SO_4 and some of the HNO_3 or HCl is released into the gas phase. These doped films were then exposed to relevant trace gases. The uptake of the trace gases as well as the formation of reaction products released into the gas phase are monitored by Quadrupole mass spectrometry, while the IR-spectra allow to follow changes in the solid phase.

ON THE ROLE OF HETEROGENEOUS PROCESSES ON THE SULFATE AEROSOLS IN ESTIMATION OF THE IMPACT OF MOUNT PINATUBO ERUPTION AND SUPERSONIC AVIATION ON THE OZONE LAYER

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2-D zonally-averaged dynamical/radiative/photochemical model of the troposphere and stratosphere is used for study of global impact of mount Pinatubo eruption (June 15, 1991) and NO_x and SO_2 emission from supersonic aircraft in the period of 1990-2015 on the ozone layer. A model takes into account aerosol physics for calculation of a sulfate aerosol layer consisting from particles with size $0.0064\ \mu m \le r \le 5.2\ \mu m$. It is shown that volcanic discharges and supersonic aviation emission of SO_2 cause a many-times increase of effective surface of sulfate aerosol particles in the entire studied range. In the case of Pinatubo eruption, due to heterogeneous processes $ClONO_2 + H_2O(s) \rightarrow HOCl + HNO_3$, $ClONO_2 + HCl(s) \rightarrow Cl_2 + HNO_3$ and $HOCl + HCl(s) \rightarrow Cl_2 + H_2O$, on the surfaces of these particles chemically inert HCl and $ClONO_2$ transform in to active chlorine components. This leads to a significant decrease in total ozone, especially in tropical latitudes and over Antarctica. In the case of NO_x and SO_2 supersonic jet emission, N_2O_5, $ClONO_2$ and $BrONO_2$ hydrolysis reactions on the surface of sulfate aerosol layer particles lead to almost a five-times decrease in extra NO_x components as compared to gas-phase chemistry. The latter causes a significant decrease in the ozone depletion. This effect still more increases (about double) when SO_2 injected from aircraft in the form of sulfate particles.

ACTIVATION OF HALOGENS VIA HOBr IN THE TROPOSPHERE - A LABORATORY STUDY

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The activation of bromine via uptake of HOBr on seaspray aerosol is of great potential interest for the chemistry of the remote- and polar- marine boundary layer. Photochemically active species can be produced according to the following reaction scheme:

$$HOBr + Br^- + H^+ \longrightarrow Br_2 + H_2O$$
$$HOBr + Cl^- + H^+ \longrightarrow BrCl + H_2O$$
$$XBr + h\nu \longrightarrow X + Br \qquad (X = Br, Cl)$$

Subsequent reactions of these halogen atoms, especially Br, with ozone, are part of an autocatalytic cycle, which, via heterogeneous processing, further destroys ozone. Laboratory experiments to investigate the interaction of HOBr with seasalt-type liquids were carried out using a wetted wall flow tube coupled to a Mass Spectrometer. Measured reactant and product concentration profiles yield uptake efficiencies and thus infomation on diffusion and reaction rate coefficients.

LABORATORY STUDIES OF HETEROGENEOUS INTERCONVERSION REACTIONS OF $ClNO_2$, $BrNO_2$ AND Br_2

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It is known that the heterogeneous reaction of N_2O_5 with chloride solution leads to the formation of $ClNO_2$. $ClNO_2$, $BrNO_2$ and Br_2 are released from mixed solutions of chloride and bromide. To get information about the possible equilibria between these species, we investigated the heterogeneous reactions of $ClNO_2$, $BrNO_2$, Br_2 on different solutions using a wetted-wall flowtube technique. $ClNO_2$ reacts fast with bromide solution to form $BrNO_2$, Br_2 and nitrite (a potential source of HONO). Hydrolysis of $BrNO_2$ is slower than that of $ClNO_2$, the observed uptake coefficient is 2.5×10^{-6}. The fast reaction of $BrNO_2$ with bromide is reversible and leads to bromine and nitrite, whereas $ClNO_2$ is formed with chloride solution. Several possible reaction mechanisms were tested and estimates of solubilities and reaction rate constants were drawn from a numerical model of the diffusion and reaction processes in the flowtube.

INDICATION FOR HETEROGENEOUS NO_3 LOSS IN THE POLLUTED ATMOSPHERE

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The night-time NO_3 lifetime was investigated during a field experiment at a polluted rural site in Germany (Jülich, 50.93°N 6.36°E) in August 1990. NO_3 was detected by differential optical absorption spectroscopy (DOAS) along a 5.8 km light path. Nine night-time NO_3 concentration profiles were recorded. The maximum NO_3 concentrations ranged from 30 ppt (parts per trillion in volume) to 280 ppt and the maximum NO_3 lifetimes ranged from about 4 minutes to 40 minutes. An investigation of potential NO_3 loss processes strongly indicates that dominating heterogeneous NO_3 losses prevailed. For the apparent ambient aerosols a temperature dependent NO_3 accommodation coefficient between 0.05 and 0.6 was deduced ($\gamma(NO_3) = 1\times10^{-24}\exp\{15500K/T\}$). Furthermore, assuming a dominant net NO_3 loss via the homogeneous reaction of N_2O_5 with water vapour, an upper limit for the reaction constant $k_{max}(NO_3 + H_2O_{(g)}) = (2.0 \pm 0.3)\times10^{-22}$ cm^3s^{-1} (T = 290 K) was calculated.

TEMPERATURE AND PSC MEASURED BY LIDAR IN THE NORTHERN NORWAY.

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The heterogeneous chemistry reactions in presence of Polar Stratospheric Clouds (PSC) allow the activation of radical species, actives for ozone depletion. The formation and the nature of PSCs is very sensitive to the temperature and to its history. The ALOMAR lidar provides since 1995 aerosol backscatter measurements, and simultaneous temperature measurements in the stratosphere on an operational basis, only limited by cloud coverage.
We will briefly present the whole lidar system and we will show a review of PSCs events during 1995 and 1996 winters, when very cold temperatures have been reached. The correlation between temperature and aerosol parameters as surface ratio is studied in order to identify different formation mechanisms. Comparison with balloonborne measurements is useful to focus on particular study cases.
Preliminary results of 1996-1997 winter, in the frame of Leewave campaign will also be presented.

GROUNDBASED DOAS OBSERVATIONS OF STRATOSPHERIC HALOGENOXIDES AT GREENLAND AND AT THE JUNGFRAUJOCH.

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During 1994/1996 stratospheric OClO has been detected solely within vortex air at Söndre Strömfjord, Greenland, by its absorption in zenith scattered sunlight. The morning behaviour of its vertical column showed the typical break between photolysis of the night-time OClO reservoir and its reformation from BrO and ClO. At solar zenith angles (SZA) of 92° the maximum vertical column was 2.5×10^{13} molec cm^{-2}. BrO was permanently present at Söndre Strömfjord as well as at the Jungfraujoch. Its variable slant columns reached up to 6×10^{14} molec cm^{-2} for SZA=88° and seemed to decrease slightly during the winter. The diurnal variations in connection with simple model considerations allows conclusions about the vertical distribution of BrO and the identity of its night time reservoir substances. An increase of BrO columns around noon which was first observed in March and July in Greenland appeared also at the Jungfraujoch. A possible tropospheric cause is discussed.

THE IMPACT OF HETEROGENEOUS REACTIONS IN SULFURIC ACID AEROSOLS ON THE CHEMICAL COMPOSITION OF THE TROPOPAUSE REGION: A MODEL STUDY

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The condensed matter of the lower stratosphere and the upper troposphere is to a high fraction composed of acidic sulfate. During the last decade many studies have shown that heterogeneous reactions in liquid sulfuric acid aerosols play an important role in the chemistry of the lower stratosphere. The subject of the present study is the impact of heterogeneous chemistry on the chemical composition of the lowermost stratosphere and the upper troposphere.
The chemisty module of the 3D mesoscale EURAD model system was modified to treat heterogeneous conversions of N-, Cl- and Br- containing species in liquid sulfuric acid aerosols. Box- and 3D-calculations were performed to investigate the effects of heterogeneous chemistry and their sensitivity to aerosol loading. A special study was dedicated to the evaluation of the impact of heterogeneous reactions on the transformation of emissions from subsonic aircraft.
The simulations show that the presence of aerosols has considerable implications for the chemistry of the regarded altitudes. Heterogeneous reactions may strongly influence the NOx/NOy ratio. They also enhance the HOx production and are responsible for an activation of chlorine and bromine radicals. As a secondary effect the ozone concentration is reduced significantly. On the other hand the aircraft induced ozone production is amplified.

LABORATORY AND MODELING STUDIES OF TROPOSPHERIC AQUEOUS PHASE CHEMISTRY

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Results from laboratory studies of the formation and reactivity of aqueous phase free radicals such as NO_3, SO_4^-, Br_2^-, Cl_2^- and RO_2 will be presented. Several laser-based methods have been developed and applied for the generation and time-resolved detection of the above species. The influence of organic compounds, including aromatics, on the chemistry within the aqueous tropospheric phase will be discussed. Results indicate that reactions of the above radicals with organic compounds may significantly change reaction sequences within droplets and aerosols dispersed in polluted airmasses when compared to clean air.
Contributions of free radical reactions to the overall chemical conversions in different tropospheric aqueous phase compartments (marine , urban continental and remote continental scenarios) will be assessed by means of the newly developed chemical aqueous phase radical mechanism (CAPRAM). This box model combines the well known gas phase RADM2 chemical mechanism with an extended set of aqueous phase chemical reactions taking into account about 200 chemical reactions in the aqueous phase. The effects of aqueous phase cloud and aerosol chemistry on tropospheric chemistry key species such as small organic peroxyl radicals and ozone will be discussed. An outlook on potential developments with regards to both modeling as well as necessary laboratory studies will be given.

AEROSOLS IN THE TROPOPAUSE REGION: VOLCANIC, AIRCRAFT, AND BACKGROUND

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A groundbased scanning lidar has been developed to investigate aerosols in the stratosphere and the upper troposphere. During periods which are not affected by explosive volcanism, source and sink mechanisms through the tropopause maintain a global level of stratospheric background aerosol, the so-called Junge layer. The enhanced layer of stratospheric sulfuric acid aerosol after explosive volcanic eruptions (e.g. Pinatubo in 1991) becomes an aerosol source to the upper troposphere. Another source of aerosols to this region is longrange commercial air traffic which is polluting the upper troposphere and the lower stratosphere. Air traffic forecasts predict an average global growth rate of aircraft movements of about 5 to 6% per year while fuel consumption will increase with about 3% per year. Both, volcanic and aircraft aerosols act as cloud condensation nuclei to modify the upper troposphere cloudiness. Similar to thin cirrus which has been observed to form occasionally at the lower boundary of the Pinatubo aerosol layer, contrails forming in the wake of aircrafts may provide surfaces for heterogeneous processes. A combined lidar - CCD camera technique is in use to investigate additional cloudiness on a regional scale in air traffic corridors.

APPLICATIONS OF HIGH RESOLUTION INFRARED SPECTROSCOPY TO ATMOSPHERIC CHEMISTRY

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We report on studies conducted at the beamline for infrared spectroscopy at the national synchrotron radiation research facility in Lund Sweden. The facilities combine a temperature controlled (90 - 350 K) multipass cell (150 m) with a high resolution Fourier transform interferometer, allowing detection in the range of 10 - 20,000 wavenumbers at 0.0012 wavenumber resolution. For typical molecules active in the infrared this implies a sensitivity to concentrations of gas phase species of 3E9 molecules/cc. We have used the instrument to study various systems involved with heterogeneous processing of chlorine compounds in the stratosphere.

HETEROGENEOUS CHEMISTRY IN AIRCRAFT PLUMES: CONSTRAINTS FOR UPTAKE COEFFICIENTS

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Recent *in-situ* emission measurements in the near-field of subsonic and supersonic aircraft exhaust plumes clearly show new volatile aerosol formation. Besides emitted non-volatile combustion aerosols (soot), volatile particle numbers exceeding 10^{16} particles per kg fuel burnt have been observed on several occasions. Microphysical models suggest that these aerosols offer peak surface area densities of $10^5\ \mu m^2\ cm^{-3}$ or more, so that heterogeneous processing can potentially become important in exhaust plumes. Under suitable conditions, contrails may form in the wake, providing typical initial water ice surfaces areas of similar magnitudes. In this contribution, we investigate characteristic timescales for heterogeneous reactions on the various particle surfaces present in diluting exhaust plumes. We will determine lower boundaries for uptake coefficients that are required for heterogeneous processing to evolve efficiently in decaying aircraft wakes. The results are applied to the particles observed in the plume of the supersonic Concorde in the lower stratosphere over New Zealand in 1994 to investigate possible uptake pathways. The potential for heterogeneous chemistry in non-persistent contrails is also briefly addressed.

A COMPARISON OF POLAR STRATOSPHERIC CLOUD MODELS USING TRAJECTORY CALCULATIONS

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As part of the CEC-supported TOPOZ (Towards the Prediction of Stratospheric Ozone) project, the chemical effects of a range of possible Polar Stratospheric Cloud (PSC) models are compared by using a photochemical box model integrated along Arctic isentropic trajectories computed using analysed winds. A PSC scheme which allows a choice of particles (ternary liquid aerosols, sulphuric acid tetrahydrate, nitric acid trihydrate and ice) in thermodynamic equilibrium is included in this formulation to determine the rates of the key heterogeneous reactions. Firstly, we present the results of calculations including the reactions of nitrogen and chlorine species on PSC surfaces. In addition, we investigate the potential rôle played by heterogeneous bromine reactions, focussing on the uncertainties that remain in reaction probabilities on solid particles. Finally, the results are compared with sample data from UARS, to give an indication of which models, if any, are appropriate for modelling Arctic PSCs.

THE MOLECULAR DIFFUSION TUBE: MEASUREMENT OF RESIDENCE TIMES OF GAS MOLECULES ON SURFACES

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A new apparatus has been designed in order to gain a quantitative understanding of the residence time of a gas molecule on a given surface: the molecular diffusion tube. The experiment, carried out under molecular flow conditions, involves sending a pulse of molecules through a narrow tube coated with a material of interest. The tube is typically 1 to 2 cm in diameter and up to 1 m in length. Since the number of gas-wall collisions in the tube is well defined and only dependent on the tube geometry, information on the magnitude of the interaction per collision can be extracted from the arrival time trace, measured by mass spectrometer at the exit of the tube. First results indicate that the residence time of water on room temperature Pyrex glass is of the order of 0.2 ms. An upper limit of 3 μs was measured for water on Teflon (PTFE). Nitrogen dioxide behaved like an ideal gas in both cases.
A Monte Carlo computer model which simulates interactive as well as non-interactive molecular gas flow through a given reactor geometry shows excellent agreement with the experimental data. Implications of our findings on the measurement of heterogeneous atmospheric rate constants in the laboratory will be discussed.

THE ROLE OF BROMINE OXIDE AND PEROXY RADICALS DURING ARCTIC OZONE DEPLETION EVENTS IN NY ALESUND.

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Depletion of ozone in boundary air during the arctic spring is known to be connected to bromine chemistry. During the EC-sponsored Arctic Tropospheric Ozone Chemistry (ARCTOC) campaigns at Ny Alesund, Spitsbergen, in April 1995 and 1996 BrO levels of 15 to 30 ppt have been found together with ozone decreasing from 40 ppb to virtually zero in air which extended to 1000m a.s.l. Those trace gases were observed by differential optical absorption spectroscopy (DOAS) along two lightpaths between 20 and 475m a.s.l. at various separations from ground. During sunny periods up to 8 ppt peroxy radicals were found by chemical amplification around noon (ROx-Box). The discussion will concentrate on the chemistry in comparison with that described by a chemical box model. The meteorological conditions and the back trajectories argue in favour of a primary halogen activation from the pack ice and its continuous recycling by heterogeneous reactions.

HETEROGENEOUS CONVERSION OF NITROGEN OXIDES ON $NaNO_3$ AEROSOL SURFACES

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The conversion of N_2O_5 to HNO_3 on wet aerosol surfaces is the dominant tropospheric removal mechanism for NO_x during the night and in the wintertime:

$$N_2O_5 + H_2O_{Aerosol} \longrightarrow 2\,HNO_3.$$

The heterogeneous N_2O_5 hydrolysis on $NaNO_3$ aerosol was studied in a large reaction chamber with a volume of 260 m^3 and a surface/volume ratio better than 1 m^{-1}. N_2O_5 was produced in-situ by addition of O_3 to NO_2. The particles were generated by a nebulizer consisting of ten 'two-fluid' nozzles. The inital $NaNO_3$ aerosol number concentrations were up to $3{\cdot}10^5$ cm^{-3}. The initial size distributions showed a CMD of 220 nm with a GSD of 2.07. Rapid coagulation lead to lifetimes of about 23 hours and to a CMD shift to larger sizes. Aerosol measurements were performed using an electrostatic classifier (SMPS, size range 0.02 to 1 µm) and a scattered light measuring system (PCS, size range 0.5 to 20 µm). The mixing ratios of the reactants NO_2, N_2O_5, and HNO_3 were measured simultaneously by high resolution FTIR spectroscopy, whereas O_3 and NO were monitored by UV absorption and chemiluminescence, respectively. In the presence of $NaNO_3$ aerosol a highly accelerated conversion of N_2O_5 to gas-phase HNO_3 was observed. The experimental results can be explained by an approximation of the heterogeneous process as a simple gaskinetic collision of N_2O_5 with the aerosol with an effective uptake coefficient γ of 0.01-0.001.

THE USE OF IN SITU MEASUREMENTS OVER ANTARCTICA TO CLASSIFY POLAR STRATOSPHERIC CLOUDS.

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Polar stratospheric clouds (PSCs) play a major role in the destruction of ozone over Antarctica, by providing suitable liquid or solid particle surfaces for complex heterogeneous chemistry. The chemical composition and physical state of PSCs are not known accurately, although it is known that water and nitric acid are involved in the condensation process on pre-existing sulfuric acid solution droplets.

The main objective of this study is to analyze in situ aerosol data in terms of their temperature-volume relationship, and to compare these relationships with results from thermo-dynamical/chemical models of temperature-volume association. The temperature, aerosol volume, pressure, water vapor and sulfuric acid mixing ratio data were obtained from in situ aerosol measurements over McMurdo, Antarctica, during southern hemisphere spring and winter seasons. Profiles of nitric acid were obtained from CLAES and MLS satellite data for the same region and time period. Measurements from day to day were grouped based on the potential temperature. Preliminary results show that liquid aerosols are slightly more common than solid aerosols in the PSCs studied.

HETEROGENEOUS REACTIONS OF OZONE AND NITROGEN COMPOUNDS AT THE SURFACE OF SOOT PARTICLES

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Combustion engines emit significant amounts of soot particles into the troposphere and stratosphere. Heterogeneous reactions at the soot surface may have an impact on the concentration of trace species like ozone and NO_x due to surface reactions and may therefore e.g. influence the ozone chemistry. The importance of such processes in competition with the gas-phase chemistry depends on their reaction probabilities and reaction mechanisms which are only poorly known.

We perform aerosol chamber experiments and run aerosol models to investigate such processes. Various soot aerosols from carbon sparc generators and flames are used and the experimental conditions are chosen to be close to atmospheric ones. The temperature can be varied between -90 and +60°C. The models describe the dynamic behaviour of soot aggregates as well as gas-phase and surface chemistry. First results on the reactivity of soot particles with respect to O_3, NO_2, and mixtures of ozone and nitrogen compounds will be discussed.

EXPERIMENTAL FINDINGS FOR HETEROGENEOUS OZONE DESTRUCTION IN CLOUDS AT MT. BROCKEN

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Theoretical studies using models with coupled gas and liquid phase chemistry suggested that not only the net formation of ozone could be reduced in clouds but also heterogeneous destruction could be possible. Several possible pathways of ozone sinks in clouds we discussed recently concerning first experimental findings of ozone depletion at Mt. Brocken. We often observed in the continuous record of ozone concentration that with passing clouds the ozone concentration decreases rapid, where the interstitial concentration is up to 50% lower than before the cloud event [Acker et al., 1995]. When the cloud is moved away, the ozone concentration increased again too around its former level. From the data set (more than 3000 1-hour samples) we found significantly differences in the chemical concentration of cloud water between events with and without ozone depletion. Using 3d back trajectory calculations and information on mesoscale cloud and precipitations fields we believe to support the idea of ozone depletion within clouds. The aim of this paper is to show a statistically significant effect of ozone depletion within clouds. Moreover, we would like to stimulate the discussion on the importance of heterogeneous processes for the mesoscale oxidant budget.

IONIC SPECIATION IN COLD SULFURIC ACID

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The ionic speciation of 10 to 80 wt % sulfuric acid has been investigated by Raman spectroscopy in the temperature region 295 to 213 K. The spectra of 10 to 70 wt % have been analyzed in terms of HSO_4^- and SO_4^{2-}, while solutions of more than 70 wt % probably also contain undissociated sulfuric acid. For all the solutions studied the degree of dissociation increases with decreasing temperature; the largest temperature dependence was observed for solutions around 50 wt %. A expression for the ionic speciation in sulfuric acid as a function of temperature and composition is presented. The observed ionic speciation is in good agreement with thermodynamic predictions for the more dilute solutions whereas there is a substantial discrepancy for concentrations above 50 wt %.

PEROXO SULFUR SPECIES IN COLD SULFURIC ACIDS, GENERATED BY NITRATE RADICALS

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Raman spectroscopy in combination with titrimetry has been used to study the speciation of mono- and diperoxo sulfuric acids in sulfuric acid solutions of stratospheric relevance. At the time of submission only a qualitative conclusion can be made: Hydrogen peroxide does enter into equilibria with the peroxo acids under the circumstances. Equilibrium constants and rates are our objectives.

The peroxo species are thought to be formed by uptake of nitrate radicals during nighttime, followed by radical exchange with sulfate ions.

IS NIGHTTIME OXIDATION OF HCl BY NITRATE RADICALS IMPORTANT ON THE STRATOSPHERIC AEROSOL?

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A chemical model assuming a monodisperse sulfuric acid aerosol with droplet size 0.1 μm has been constructed. The model environment is assumed to be that of the mid-latitude lower stratosphere. The principal physical and chemical reactions taken into account are 1) (nighttime) uptake of nitrate radicals, 2) conversion of sulfate into sulfate radicals through reaction with nitrate radicals 3) conversion of water into hydroxyl radicals through reactions with either nitrate or sulfate radicals. Finally reactions of any of the radicals above with dissolved HCl to form Cl and subseqently Cl_2, which is then assumed to evaporate from the droplets.

Chlorine formation competes with build-up of peroxosulfuric acids and at the present stage the latter proces is favoured over the former according to the model.

DIFFUSIVITIES IN COLD SULFURIC ACIDS

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The diffusivities (D) of several compounds found in the stratosphere are needed for modeling purposes. We have measured D for DMSO (dimethyl sulfoxide), DMSO2 (dimethyl sulfone) and $HDO/HDSO_4$ in 80, 70 and 60% D_2SO_4 and at -25°C, 0°C and 25°C. Measurements of the diffusivity of ^{15}N-nitrate is underway. Attempts to measure $D_2^{17}O$ and $D_2SO_3^{17}O$ have failed sofar, but attempts continue.
Using the Einstein-Stokes relation $D = C\frac{T}{\eta}$, where η is the (known) viscosity (function of temperature T), C was determined for the three acid concentrations for the substances mentioned.

OBSERVATION OF BROMINE-MONOXIDE IN THE LOWER ATMOSPHERE BY GROUNDBASED REMOTE SENSING AND ITS SIGNIFICANCE FOR THE GLOBAL BROMINE BUDGET.

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Tropospheric BrO has been observed by groundbased zenith sky spectroscopy during tropospheric solar sunrise in the Arctic as well as in the Antarctic. Here we report on the observation of inorganic bromine compounds in tropospheric air at Söndre Strömfjord, Greenland in July/August 1995. Increasing BrO absorptions below a solar zenith angle of 80° were found to occur symmetrically around noon. That phenomenon can be explained by the competition of the increasing photolysis rate of bromine nitrate during a.m. and its reformation. The latter becomes overwhelming again towards sunset. The backtrajectories point to the Arctic as an important source of atmospheric bromine as already observed in several investigations and also during ARCTOC.

DIFFUSION AND SOLUBILITY OF STRATOSPHERIC TRACE GASES IN COLD AQUEOUS SOLUTIONS OF SULFURIC ACID

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Heterogeneous processes are known to play important roles in the chemistry of stratospheric ozone. In constructing models of heterogeneous reactions occuring in the stratosphere, a complete data set for the involved physico-chemical processes in the gas and particle phases is required.
We have improved a recently developed capillary column method to measure diffusion coefficients and solubilities of trace gases in thin film sulfuric acid solutions (film thickness between 1 and 2 µm, 40 to 80 wt% sulfuric acid) at stratospheric temperatures down to -90°C. The trace gases are detected using a novel ion trap mass spectrometer. The experimental approach is described on the poster and first results are discussed.

ADSORPTION OF HCl ON ICE WITH KNOWN SURFACE AREA

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The adsorption of trace gases on solids are key steps in numerous atmospheric chemical processes. One of the essential parameters that characterize adsorption is the surface coverage θ of the gas on the solid as a function of trace gas partial pressure. In most cases, however, such as the adsorption of HCl on ice, as relevant to ozone depletion, large uncertainties remain on the surface coverage because the specific surface area of the ice used in the adsorption experiments was never actually measured.
We have therefore built a new system where we can determine the ice surface area and porosity before and after our HCl adsorption experiment. Results dealing with the adsorption of HCl on various types of ices (natural snow, porous and non porous ices), at different temperatures, will be presented and compared with previous results by other authors to stress the importance of the characterization of the solid in the interpretation of adsorption experiments.

CHEMISTRY AT THE SURFACES OF MODEL STRATOSPHERIC CLOUD PARTICLES

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Chemical reactions that occur in the surface and near surface regions of ice and sulfuric acid particles play a critical role in formation of the Antarctic ozone hole. We seek to understand the underlying mechanisms of these surface-mediated chemical transformations. Our experimental method involves the study of ultrathin (<200 Å thick) films of ice and sulfuric acid as surrogates for polar stratospheric cloud particles. The films, which are deposited on single-crystal metal substrates, serve as convenient samples on which to study adsorption and desorption kinetics, and adsorbate structure. Importantly, the large surface area to volume ratios of the films make it experimentally simple to distinguish between surface- and bulk-mediated processes. The following aspects of our recent work will be discussed: (i) the extent to which ice surface structure dictates reactivity, (ii) the surface chemical properties of solid and liquid sulfuric acid, (iii) the thermal and photochemistry of stratospherically abundant chlorine oxides on ice, and (iv) the mechanistic consequences of the fact that the surface of an atmospheric ice particle is highly dynamic, i.e. the evaporation and condensation rates of water on ice are very large.

A REMPI-MS technique to monitor selected atmospheric trace constituents in the ppt range

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Resonance enhanced multiphoton ionisation (REMPI) in a supersonic molecular beam in combination with a mass spectrometer (MS) has been established as a highly selective and very sensitive detection method in the analysis of trace constituents of the atmosphere.

In this work a new set-up for the MS gas inlet and the ion source are presented for on-line measurements of traces with ppt concentrations at atmospheric pressure. The ionisation region was placed in the expanding jet directly behind the gas inlet nozzle. The increase in sensitivity is based on the high particle density in the ionisation region and the cooling through adiabatic expansion. The geometry of the nozzle and the skimmer in the ion source were optimised by ion trajectory calculations.

In the presented experimental set-up detection sensitivities were achieved in the range of 1-10 ppt for different trace gas compounds (NO, CH_3CHO, aromatics). The detection limits have been determined in He, Ar and synthetic air and were found to be independent on the carrier gas. This technique is about 500 times more sensitive than other known methods.

LAMOCS: A EUROPEAN RESEARCH PROJECT INVOLVING LABORATORY AND MODELLING STUDIES OF HETEROGENEOUS REACTIONS IN THE STRATOSPHERE

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LAMOCS (= Laboratory Studies and Modelling of Heterogeneous Chemistry in the Stratosphere) is a research project funded by the European Commission and jointly performed by 8 laboratories (Alfred Wegener Institute Bremerhaven (O.Schrems), University of Copenhagen (T. Pedersen), University of Helsinki (M. Räsänen), University of Lund (B. Nelander), Norewegian Institute of Air Research, Kjeller (F. Stordal), Technical University of Vienna (E. Knözinger), University of Hannover (H. Willner) and the University of Oslo (C. Nielsen)). The main goals are studies of heterogeneous chemical processes which take place on stratospheric sulphuric acid aerosol (SAA) and which influence the partitioning of hydrogen, halogen and nitrogen species in the lower stratosphere over middle to high latitudes. All laboratory investigators in the LAMOCS project use a common reaction medium of a composition close to that of the stratospheric aerosol, i.e. 60-80 wt% sulphuric acid in water with trace constitutents added in the right quantities. Two different models - a two-dimensional model and a trajectory model - are used in this project to study the effects of new chemical reactions that are investigated in the laboratories. The chemical scheme in the trajectory model is identical to the one used in the 2-D model, including gas phase and heterogeneous reactions. Backward trajectories are calculated on given isentropic surfaces and they are based on the ECMWF winds. An overview of the project and results obtained from the participating laboratories will be presented.

UPTAKE OF ORGANIC COMPOUNDS BY LIQUID WATER: A DROPLET TRAIN STUDY

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Organic compounds are important for a correct description of the atmospheric chemistry. They may be directly emitted by both natural and anthropogenic sources or be present as secondary pollutants. In this latter case, they may be produced, for example, during the degradation of methane, dimethyl sulphide or aromatics leading, respectively, to methyl hydroperoxide (CH3OOH), methanesulfonic acid (CH3SO3H) and glyoxal (CHOCHO). All these species may interact with the atmospheric condensed phase (fog, cloud) and act as oxidants, or oxidation inhibitors or finally as aerosol precursors. It is therefore important to understand how efficient these gas/liquid interactions may be. We performed such a study using the droplet train technique. Current results describing the effect of temperature, aqueous phase composition on the uptake rate will be presented.

KINETICS OF THE UPTAKE OF NO_3 ON NACl AND KBr SALT

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The NO_3 radical is known to play an important role in tropospheric nighttime chemistry. We measured the uptake kinetics of NO_3 on NaCl and KBr salt using a low pressure flow reactor equipped with MS and LIF detection. NO_3 was produced *in situ* by thermal decomposition of N_2O_5 resulting in a yield of 50 % NO_3 and 150 % yield in NO_2 with respect to N_2O_5. The uptake of NO_3 on NaCl and KBr powder (100-160 µm grain diameter) was found to be fast with an uptake coefficient of $\gamma = 0.1$. Furthermore, we found a strong dependence of the NO_3 uptake on the total external surface area of the salt sample. By using salt samples of well-defined total external surface and applying a diffusion correction to the obtained uptake rate of NO_3 we are able to determine the true uptake coefficient γ_0.

It is assumed that atomic Cl and Br are the products of the reaction between NO_3 and the corresponding salt. However, during the reaction of NO_3 with NaCl HCl was observed as the only gaseous product in 100 % yield with respect to NO_3. BrO and Br_2 were identified as reaction products of the reaction of NO_3 with KBr. All observed products may be formed in secondary reactions of the halogen atom and additional experiments are underway with the goal to study the primary products of the NO_3/salt heterogeneous reaction.

HETEROGENEOUS CONVERSION OF NITROGEN OXIDES AT URBAN CONENTRATIONS AND LOW HUMIDITIES

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The heterogeneous conversion of nitrogen oxides to HNO_3 on aerosol surfaces is the most important tropospheric loss path for NO_x during the night and in the wintertime. The nocturnal chemistry of the NO_2/O_3 system was studied at urban atmospheric NO_x concentrations and low relative humidities (< 2%). The experiments were performed at ambient temperature and pressure in a large reaction chamber with a volume of 260 m^3 and a surface/volume ratio better than $1m^{-1}$. The organic aerosols formed upon the addition of O_3 to NO_2 in ambient air. The mixing ratios of NO_2, N_2O_5, and HNO_3 were measured simultaneously by high resolution FTIR spectroscopy. Since the experiments were carried out at maximum N_2O_5- and HNO_3-mixing ratios of a few ppb, a three mirror type White cell with an optical path length of up to 720 m, modified by two pairs of diagonal flat mirrors, was set up. O_3 and NO were monitored by UV absorption and chemiluminescence, respectively. Aerosol measurements were performed using an electrostatic classifier (SMPS, size range 0.02 to 1 µm). Model calculations including the most important gas-phase reactions of the NO_y system could not explain the observed N_2O_5-HNO_3 conversion rate at low humidities. A possible heterogeneous reaction on organic aerosols will be discussed.

THE EVOLUTION OF POLAR STRATOSPHERIC CLOUDS ABOVE SPITSBERGEN

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Multiwavelength lidar observations of Polar Stratospheric Clouds (PSCs) are performed at the Arctic NDSC primary station in Ny-Ålesund, Spitsbergen (79°N, 12°E) since winter 1991/92. The Spitsbergen lidar data represent the 'normal' development of Arctic PSCs in the center of the Arctic vortex. The high variability of the minimum temperatures in the Arctic is reflected in the observation frequencies of PSCs. PSCs above Spitsbergen are mainly of type I, as temperatures only seldom reach the water frost point. Lidar depolarization measurements in combination with back trajectory analyses of airmass thermal history of PSCs are used to distinguish distinct classes of type I PSCs. PSC observations of winter 1992/93, 1994/95 and 1995/96 were analysed to study the evolution of PSCs during the winter season. The PSC development in winter 1995/96 is regarded as typical for a 'cold' winter in the Arctic with a normal background aerosol content. The development shows three distinct appearances of the PSC layer during early, mid- and late-winter, which will be discussed.

VALUES OF ENTHALPY CHANGES IN SOLVATION REACTIONS OF IONS AND ION CLUSTERS IN SOLUTIONS

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The enthalpy changes, ΔH, for 14 solvation reactions for ions Na and ion clusters $Na^+Et_m(H_2O)_n$ in solution have been determined, using the experimental data. The solvation consists in addition one or two ethanol molecules to ions and ion clusters under equilibrium conditions:

$$Na^+Et_m(H_2O)_n + Et \rightleftharpoons Na^+Et_{m+1}(H_2O)_n \quad (I)$$

$$Na^+Et_m(H_2O)_n + 2\,Et \rightleftharpoons Na^+Et_{m+2}(H_2O)_n \quad (II)$$

(m, n = 0,1,2,...; Et - ethanol molecule). As an example, some values of ΔH, kJ/mole, are: - 30,9 (m=n=0, (I)); - 46,4 (m=n=0, (II)); - 24,7 (m=0, n=1, (I)); - 36,1(m=0, n=1, (II)); -16,7 (m=n=1, (I)); - 32,6 (m=n=1, (II)). These results have been obtained by the mass spectrographic method of field evaporation of ions out of solutions, based on evaporation of these ions in vacuum by a strong electric field [1]. There is no any other methods for the ΔH determination in solutions. In experiments the solution of NaI in water-ethanol solvent was used; concentration of NaI was 0,08 mole/l, the mole portions of ethanol and water were 0,76 and 0,24 correspondently. The solution temperature was in region of 219-248 K.

[1]. N.B.Zolotoy, G.V.Karpov. Doklady Physical Chemistry, 1996, v.348, No.4-6, p.137.

Airborne Polar Experiment: the 1996-1997 winter Arctic Mission, Rovaniemi, Finland

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The first mission of the Airborne Polar Experiment (APE) will be performed in Rovaniemi, Finland, from December 1996 to January 1997. The mission will use a Russian high-altitude aircraft, the M55 Geophysica, and aims to study the characteristics and formation processes of polar stratospheric clouds (PSCs). It is planned that the aircraft will fly directly inside PSCs at altitudes of up to 21 km, investigating the effects of the Scandinavian Alps on PSC formation, and carrying out the first search for PSC activity over the Ural mountains. The payload is composed of several in-situ and remote sensing instruments, which will measure particle size distributions and backscatter characteristics, short-lived chemical species including ClO, ozone, and water vapour. Dynamical, chemical and microphysical modelling will be drive and assist development of the campaign. The APE campaign will be co-ordinated with the POLECAT mission. POLECAT will use a DLR falcon aircraft equipped with the OLEX Lidar system, in combination with sophisticated mesoscale dynamical modelling and microphysical calculations, to study lee wave PSC events.

OA29/ST24 The role of vegetation emissions in tropospheric chemistry

Convener: Versino, B.
Co-Convener: Hewitt, N.

EMISSION OF TERPENES AND ISOPRENE FROM THE DIFFERENT OAK SPECIES *Quercus ilex* L., *Quercus pubescens* L. AND *Quercus agrifolia* L.

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The objective of our study within the frame of the EU-project "B.E.M.A." was to compare the monoterpene and isoprene emissions of two important oak species representative for the Mediterranean ecosystem, namely, *Quercus ilex* (Holm oak), a strong monoterpene emitter, and *Quercus pubescens* (White oak), a strong isoprene emitter. Additionally we included the Californian oak species *Quercus agrifolia* (Coast Live Oak), which is anatomically and morphologically comparable with *Quercus ilex*. The data show that Live Oak and Holm oak, though looking identical, differ as far as the emission of terpenoids is concerned, emitting isoprene or terpenes, respectively. Data from simultaneous measurements of the isoprene emitting White oak and the monoterpene emitting Holm oak as well as additional investigations on *Quercus agrifolia* (Coast Live Oak) fit perfectly with an algorithm, describing the emission as being dependent on light and temperature. The dependence of monoterpene emissions from PAR and temperature and the similar behaviour of isoprene and terpene emitters points to close metabolic pathways, which is in full agreement with recently described evidence for the production of *Q.ilex* monoterpenes by the same pathway as known for isoprene. Hence, modelling terpene emissions for the main Mediterranean oak species can be performed by the same procedure as for isoprene.

FLUXES OF SEVERAL VOC EMITTED BY ORANGE TREES DETERMINED BY THE VERTICAL GRADIENT METHOD

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Orange tree orchards extend over large areas along the Spanish Mediterranean coast and their emissions of organic substances like limonene, linalool, etc., are likely to play a role in atmospheric photochemistry leading to ozone formation. It is therefore essential to gain knowledge on the emission fluxes of these compounds. During two measuring campaigns, conducted in the frame of the BEMA project of the European Commission, in July 1995 and in April-May 1996, the surface fluxes of a series of volatile organic compounds were determined using the vertical gradient method. The concentration gradients were measured at three levels through an automated sampling system and GC-MS analysis. The eddy diffusion coefficients were derived from sonic anemometer data. The gradients observed were mostly monotonous, indicating a good homogeneity, checked by other observations. VOC emissions, dominated by limonene, linalool and sabinene, followed a daily trend similar to that of evapotranspiration fluxes, indicating that stomatal processes could be in part responsible for the emission.

A LABORATORY SCREENING STUDY OF MEDITERRANEAN OAK SPECIES FOR VOC-EMISSIONS

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The oak genus, in the Fagaceae family, consists of about 450 different species world-wide. Among the many peculiar qualities, oaks are also of special interest in air chemistry, since they are emitting reactive volatile compounds. Reactive volatiles of biogenic origin are supposed to play a key role in air chemistry, e.g. affecting the OH-radical budget, the ozone and particle formation. In the US, oaks are by far the most dominant isoprene source, due to their dominant biomass and high emission rates. US inventory methods and algorithms have previously been applied for Europe. Through the findings of the BEMA-project, European inventories are modified, since many Mediterranean oaks emit high amounts of monoterpenes.

In order to get a better understanding of this surprising finding, we have performed a screening study of 10 European and 2 North-American (semi) evergreen oaks (not screened previously), to characterize the variability and evolutionary pattern of oak emissions, and to complement the BEMA field studies. We used a special minicuvette system for sampling. Chemical analysis of emitted compounds was performed using GC-FID and GC-MS. We could separate the following four emitter types: 1) strong isoprene, 2) strong monoterpenes, 3) mixed isoprene + monoterpenes, as well as 4) non-emitters. Results are discussed with respect to implications for presently used emission scenarios.

APPLICATION OF THE REGIONAL ATMOSPHERIC CHEMISTRY MECHANISM (RACM) TO THE STUDY OF BIOGENIC EMISSIONS IN THE BEMA-BURRIANA TEST-SITE

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Due to its deleterious effect on human health, agricultural crops and forest ecosystems, tropospheric ozone continues to be of significant concern worldwide. The fundamental question to solve in environmental atmospheric chemistry is the following: "To reduce tropospheric ozone levels in impacted urban, suburban and rural areas, should one control VOC, NOx, or both simultaneously, and to what degree?". The same question holds for other air polluting compounds, such as benzene, PAN, PAH and organic particles). The potential importance of biogenic VOCs (in relation to anthropogenic VOCs) for ozone control strategies is evident from the suggestion that the BVOC emissions may be so large that even a 100 % control of AVOCs would not be sufficient to meet air quality standards.

In the present work the RACM boxmodel mechanism (developed at the IFU, Garmisch-Partenkirchen) is applied to study the influence of isoprene (hard wood), α-pinene (soft wood), limonene (citrus vegetation) and AVOC emissions on the formation of ozone and other polluting chemicals in an area that is representative for the BEMA-Burriana test-site.

TROPOSPHERIC OXIDATION OF MBO

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MBO (2-methyl-3-buten-2-ol), a C_5 unsaturated alcohol, was recently found to be an abundant volatile organic compound (VOC) of biogenic origin present in the atmosphere.

Generally, VOCs emitted from vegetation into the atmosphere are removed by reaction with atmospheric oxidants such as OH radicals, ozone and NO_3. During daylight hours, reactions with OH radicals and ozone are usually the most important removal processes, while the reaction with NO_3 can be a major sink at night.

In the present study we have attempted to identify the carbonyl products of MBO's oxidation under simulated atmospheric conditions using a 480 L Teflon coated reaction chamber coupled with a FT-IR spectrometer. Acetone was found to be among the main products.

OZONOLYTIC FORMATION OF 6-METHYL-5-HEPTEN-2-ONE AND 4-OXOPENTANAL FROM HIGH MOLECULAR WEIGHT COMPOUNDS ON LEAF SURFACES

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The present study explains the occurrence of 6-methyl-5-hepten-2-one in ambient air and reports for the first time the presence of 4-oxopentanal.

We have conducted a series of laboratory experiments in which it is demonstrated that significant amounts (> 10 ng/L) of 6-methyl-5-hepten-2-one and 4-oxopentanal are formed by the reaction of ozone (50-100 ppbv) with foliage of common vegetation in the Mediterranean area (Citrus > Quercus >Pinus). In order to ascertain that the formation is chemical, as opposed to biological, epicuticular waxes were extracted from the leaves, dispersed on glass wool and reacted with ozone. Again, significant amounts of 6-methyl-5-hepten-2-one and 4-oxopentanal were detected. A number of high molecular weight components were identified as potential precursors of 6-methyl-5-hepten-2-one and 4-oxopentanal by their surface reaction with ozone. The most potent of the investigated compounds were the tertraterpene squalene and the sesquiterpenes nerolidol and farnesol. The atmospheric lifetime of 6-methyl-5-hepten-2-one can be calculated from published data to approximately 1 hour at Mediterranean summer conditions. For the present study, we have synthesised 4-oxopentanal and investigated the kinetics of its gas-phase reaction with OH, NO_3 and O_3. A lifetime longer than 10 hours was calculated from the measured reaction rate constants.

ESTIMATION OF THE ORGANIC ACID EMISSION-POTENTIAL OF A MEDITERRANEAN TREE SPECIES BASED ON ACID CONCENTRATIONS IN AND CHARACTERISTICS OF THE PLANT APOPLAST

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Direct (or indirect) emission of acetic and formic acid from higher plants is regarded to be a significant source for these acids found in the the atmosphere. Considering the pathway from the plant cell to the atmosphere, a gas molecule first has to leave the liquid phase and has to reach the internal leaf gas phase. Within this context the apoplast (cell wall) is the last barrier before the molecule can escape through the stomata. Under the frame of the EU-project B.E.M.A. we followed the diel concentration patterns of apoplastic ions and organic acids in close relation to the physiological activities of *Quercus ilex L.* leaves in parallel to measurements of the emission. Concentrations in the apoplastic sap were found between 0 (not detectable) and 320 μmol/l for acetic and between 0 (not detectable) and 70 μmol/l for formic acid. Lowest concentrations were detected around noon and the highest concentrations were found in the morning and late evening. The exchange rates of acetic and formic acid followed a typical diel pattern and ranged between -10 and 52 [nmol/(m² min)] with the maximum around noon. We compared real emission rates with theoretical ones by calculating the theroretical emission capacity using the Henry's law constants for acetate and formate and apoplastic pH values between pH 4 and pH 5. The comparison showed that 26 to 130 % of the acetic acid emission can be explained. However, for apoplastic formic acid we found lower concentrations which may not be sufficient to explain all measured emission rates

MODEL INTERCOMPARISON BETWEEN THE EMEP MSC-W AND RACM ATMOSPHERIC CHEMISTRY SCHEMES

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Atmospheric transport-chemical modeling is important for understanding the impact of air-pollutant emissions, e.g. biogenic and anthropogenic, on the chemical composition of the atmosphere. Changes in the chemical composition imply consequences for the environment, e.g. changes in the concentrations of tropospheric ozone and toxic compounds as well as changes in regional depositions. The gas-phase reaction scheme is an important part of any numerical simulation of transport and transformation of trace gases.
In this paper an intercomparison of the EMEP MSC-W scheme and a recently developed chemical scheme, RACM, is presented. The schemes are used for tropospheric gas-phase chemistry research. The main difference between the RACM and EMEP MSC-W mechanisms is that the RACM mechanism has a more detailed representation of atmospheric organic chemistry.
The intercomparison is based on a series of (zero dimensional) box calculations for scenarios involving biogenic emissions and a polluted atmospheric boundary layer. The scenarios include emissions of a variety of species which are representative for continental European air. The intercomparison involves: influence of clouds on the photochemical reactions, different photochemical schemes, sensitivity analyses and uncertainty analyses.

THE INFLUENCE OF TEMPERATURE ON BIOGENIC EMISSIONS AND OZONE CHEMISTRY

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Volatile organic compounds (VOC) and NO_x are the main precursors of ozone and other photooxidants in the troposphere. VOC are emitted by human activities and by plants. NO_x emissions are also caused by human activities and by microorganisms in the soil. Biogenic VOC emissions depend on the land use and on environmental conditions like temperature and the photosynthetic active radiation (PAR). The biogenic emissions of NO_x are a function of land use, surface temperature, fertilizer usage and precipitation events. The temperature dependence of the biogenic VOC and NO_x emissions is exponential and therefore it is necessary to have accurate temperature data in order to determine accurate biogenic emission data. The same is true for PAR.
Sensitivity studies of the influence of temperature on the biogenic emissions and the ozone chemistry are shown. The studies are carried out with a boxmodel, a one-dimensional and a complete three-dimensional version of the comprehensive mesoscale model system KAMM/DRAIS with the implemented RADM2 chemistry code. The results of the simulations and observations show that the temperature dependence of the ozone concentration is mostly controlled by the temperature dependence of the biogenic emissions and the thermal decomposition of PAN.

IMPACT OF BIOGENIC VOLATILE ORGANIC COMPOUND EMISSIONS ON THE OXIDAZING CAPABILITY OF THE TROPOSPHERE: A THREE-DIMENSIONAL GLOBAL SIMULATION

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A global three-dimensional chemical transport model, called MOZART (Model of Ozone and Related Tracers), is used to investigate the impact of biogenic emissions of volatile organic compounds (VOCs) on the budget of oxidizing species in the troposphere. The model domain covers the altitudes from the surface to the upper stratosphere with 18 vertical levels. The spatial resolution is about 2.8 degrees in latitude and longitude. Dynamical and physical fields calculated by the NCAR Community Climate Model (CCM3) are used to drive the transport of chemical species. The global distributions of 40 chemical species are calculated. The chemical scheme includes about 130 photochemical reactions.
In this paper, we investigate the impact of biogenic emissions of VOCs on ozone and hydroxyl radical distributions. A special attention will be focused on isoprene and terpenes emissions. Different emission inventories of biogenic emissions are compared to site measurements and introduced in the global model. The impact of the different emission estimates on the global budget of CO is presented.

ATMOSPHERIC MEASUREMENTS OF ORGANIC TRACE GASES BY IMRMS

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Using an IMRMS (Ion Molecule Reaction Mass Spectrometer) including also a novel ion trap mass spectrometer various atmospheric trace gases were measured and feasibility studies for such measurements were made. Trace gases investigated include acetone, methylcyanide, hydrogencyanide, methanol and organic acids. Making use of the MS^N (n-th generation fragmentation studies) potential of the ion trap mass spectrometer allows the identification of mass peaks and kinetic studies of the observed ions.

CONTRIBUTION OF BIOGENIC VOC TO THE FORMATION OF OZONE IN A RURAL LOCATION IN NORTH-EASTERN GERMANY

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Atmospheric concentrations of C_6-C_{15} hydrocarbons and C_4-C_{12} oxygenated volatile organic compounds (VOC) including alkanes, aromatics, monoterpenes and aldehydes were measured during the POPCORN campaign (Photo-oxidant formation by plant-emitted compounds and OH-radicals in North-Eastern Germany) in August 1994. During this field campaign also VOC-emissions from several crop and tree species and the ambient concentrations of CO, C_2-C_7 nonmethane hydrocarbons (NMHC), light aldehydes, nitrogen oxides, ozone and hydroxyl radicals (OH) were measured. These data are used to discuss the VOC measurements.
α-Pinene and Δ3-carene, most probably originating from pine-forests about 1 km away from the measuring site, were the most abundant biogenic hydrocarbons, but in most samples also n-pentanal, n-hexanal, n-nonanal and n-undecanal were present. As emission studies indicate, these highly reactive compounds originate most probably from emissions from maize.
From the measured concentrations of methane, CO, C_2-C_{15} NMHC and C_5 - C_{11} aldehydes a photochemical production of ozone in the order of 3.5 ppb/h can be estimated by a simple first order approach. It is shown that the contribution from anthropogenic and biogenic VOC was roughly equal during POPCORN. About 20% of the ozone production can be ascribed to the turnover of monoterpenes, about 12% was due to isoprene and another 10% due to higher n-aldehydes. None of the other measured compound classes contributed more than 15%.

THE BEMA-PROJECT: SCALING UP THE BIOGENIC EMISSIONS FROM TEST SITES TO LANDSCAPES

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On the basis of measurements of emission rates, Leaf Area Indices (LAI) and biometric data for about 20 species and 15 land-cover types, a scaling up of biogenic emissions is presented. It includes the application of different procedures for scaling up, by combining parameters (e.g. LAI, biomass, vegetation coverage, canopy layering, insolation) with emission rates and algorithms in a spatial model. This approach consists of the following steps: (i) elaboration of a pseudo-three dimensional Geographical Information System (GIS) for the test sites in Italy, France and Spain, (ii) calculations of relations between diameter at breast height (dbh), biomass and LAI, (iii) application of an insolation and light interception model in the stands for one to two canopy layers and surfaces, (iv) based on emission rates for pine, holm oak and orange trees as well as standardized emission factors for light, classified incoming light is driving the diurnal and seasonal course of emissions for the test sites. Calculations of total emission fluxes are intercompared according to the different formulas and parameter combinations, e.g. the relevancy of spatial effects. Some results of the GIS model for insolation and light interception are shown to strengthen its usefullness in sparse vegetation and complex terrain.

RELATIONSHIPS BETWEEN E/A RATIO AND MONOTERPENE EMISSIONS IN TWO EVERGREEN COMMUNITIES

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Within the frame of the Biogenic Emissions in the Mediterranean Area project aimed at assessing the emission of volatile organic compounds from Mediterranean plant species, a work was performed in which ecophysiological data were collected with single-leaf cuvettes in the field. These data are useful for: 1) extrapolating data to the entire canopy through up-scaling processes; 2) assessing whether data collected could have been used to get emission figures that were representative of the different physiological situations experienced by the plant in our sites. Gas-exchange measurements were performed in May on *Quercus ilex* L. and *Pinus Pinea* L. growing into oak-pine forest in Castelporziano (Italy) and *Citrus sinensis* (L.) Osbeck placed in a orange grove in Burriana (Spain). Very important are the net photosynthesis (A) and leaf transpiration (E) because these parameters are related to the amount of VOC produced by the plant and released in the air measured by cuvette method. For this reason, the value between the water transpirated and the carbon assimilated (E/A) seems a useful index for better understanding the emission process related to plant species and environmental parameters. Comparing the E/A ratio and monoterpenes emission values in the various ecosystems we observe a strong correlation between these parameters, suggesting the possibility to describe the two evergreen communities on the basis of functional characters.

ESTIMATIONS OF BIOGENIC VOC EMISSIONS FROM A NORTHERN BOREAL FOREST USING THE MICROMETEOROLOGICAL GRADIENT METHOD

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Forests in the boreal regions are assumed to be a major source of volatile organic compounds (VOCs). Important hydrocarbon species emitted by vegetation include isoprene and monoterpenes. As a part of the BIPHOREP-project, aimed to quantify biogenic VOC emissions and photochemistry in the boreal regions of Europe, we have conducted a measurement campaign in northern boreal zone near the Pallas-Ounastunturi National Park in Finland in July 1996. Forest in the measurement site (67°58'N, 24°14'E) was composed mainly of mountain birch, norway spruce and scots pine. Vertical gradients of VOCs were measured above the forest canopy. Light hydrocarbons were sampled in steel canisters via teflon tubing from 19 and 31 metres and terpenes were sampled on the same heights in Tenax-tubes using automated samplers. Turbulent exchange coefficients are derived from eddy covariance fluxes using Businger-Dyer-equations. We present vertical fluxes calculated from the measurements. Error sources and estimations of the accuracy of the calculated fluxes are discussed. Temperature dependence of the emissions is also shown. The data suggests that also other environmental parameters have some effect on the emissions.

DIURNAL AND SEASONAL VARIATION OF THE EXCHANGE OF SHORT CHAINED ORGANIC ACIDS AND ALDEHYDES BETWEEN TWO MEDITERRANEAN TREE SPECIES (HOLM OAK, *Quercus ilex*; PINE, *Pinus pinea*) AND THE ATMOSPHERE

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Within the frame of the EU-project B.E.M.A. we investigate the emissions of formic acid, acetic acid, formaldehyde and acetaldehyde from Mediterranean vegetation to the atmosphere. Within joint field measurements have we explored two typical Mediterranean tree species, Holm oak (*Quercus ilex*) and pine (*Pinus pinea*) at Castelporziano (Rome/Italy), using a dynamic cuvette system flushed with ambient air. We followed the diel emission pattern and the plant's physiological activities in spring, summer and autumn. Emission measurements under the diurnal light/dark cycle showed correlations between the release of acids and light intensity, leaf temperature and transpiration of an enclosed branch but only poor correlations between the aldehyde exchange and physiological behaviour. The results suggest a direct emission from the vegetation for the acids and probably a bidirectional exchange for the aldehydes. The exchange rates of the compounds followed a diurnal as well as a seasonal pattern with maxima at noon and in the summer and ranged between -0,052 - 0,37 [nmol/(g d.w · min)] for organic acids and between -0,4 - 1,2 [nmol/(g d.w. · min)] for aldehydes. The direct emission of both organic acid species from the vegetation seems to be a significant source for the organic acid budget in the atmosphere.

THE INFLUENCE OF SOLAR UV-B RADIATION AND DROUGHT STRESS ON THE EMISSION RATE AND CONTENT OF TERPENES OF NORWAY SPRUCE NEEDLES (PICEA ABIES L. [KARST.])

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The essentials of biogenic production and emission of terpenes of Picea abies have been studied very well. It is known that several environmental and genetic factors influence the content and emission rate of these biogenic volatile organic compounds (BioVOC). Nowadays climatic changes and an increase of UV-B radiation have been predicted. A feedback of changed climatic factors in combination with an enhanced UV-B radiation can not be excluded. Further investigations have to be done to update the role of BioVOC concerning tropospheric chemistry and plant physiology in view of global change processes. To test the effects of solar UV-B radiation in combination with drought stress, 4-year old clonal Norway spruce trees were investigated in a study designed as UV-B exclosure experiment. The experiment was carried out at 710 m above sealevel in Garmisch-Partenkirchen in 1995 and 1996. The spruce trees were cultivated in ventilated plant chambers equipped with UV-B transmittable plexiglas. Two variants (UV-B exclosure conditions and +UV-B=20conditions) were realized by using two types of plastic films differing in their UV-B transmittance. During the exposure time of 22 weeks UV-B radiation, as well as the climatic parameters air temperature, air humidity and soil water potential were monitored. Effects of UV-B radiation and drought stress were studied on the levels of photosynthetic gas exchange, terpene emission and monoterpene content of current-year spruce needles.

EMISSIONS OF VOLATILE ORGANIC COMPOUNDS FROM AGRICULTURALLY USED VEGETATION: AMBIENT MEASUREMENTS, FIELD STUDIES OF EMISSIONS AND LABORATORY INVESTIGATIONS

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There are large areas with agricultural crops as essentially the only vegetation. For many of these areas industrial or urban emissions are low. Atmospheric VOC chemistry over these regions may thus be dominated by emissions from the crops. However, our present knowledge of VOC emission rates from agriculturally used plants is very limited. In this study a brief overview of the emissions of VOC from vegetation will be given and results from several studies we recently conducted will be presented. These studies include laboratory studies in a controlled environment chamber under defined conditions, field studies with a mobile flow-through plant enclosure and ambient measurements above a corn field. The results show that the emission rates of VOC from agriculturally used plants under normal conditions are low, in most cases at the lower end of published emission rates. The emitted VOC are a complex mixture of various types of compounds, including a number of oxygenated substances. Higher emission rates are found under specific conditions, e.g. during flowering, but also stress of various types strongly enhances the VOC emission rates. An ambient study in a rural area of Central Europe showed that in spite of relatively low emission rates roughly 50% of the photochemical ozone production can be ascribed to VOC emitted from vegetation.

AN ALGORITHM FOR THE DETERMINATION OF EMISSION RATES OF TERPENES FROM SUNFLOWER AND OTHER PLANTS

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Emissions of volatile organic compounds from sunflower *(Helianthus annuus)* were measured in a continuously stirred tank reactor. The emission rates of isoprene, α-pinene, sabinene, limonene, an unidentified compound and the sesquiterpene caryophyllene were dependent on temperature as well as on light intensity. During darkness significant emission rates of monoterpenes were observed, too. The behaviour of the terpene emission rates with temperature and light intensity can be described by an algorithm that combines the model for the emissions originating from a pool and its temperature dependence (*Tingey et al.1991; in Trace gas emissions by plants, Acad.Press*) and the algorithm given by *Guenther et al. 1993(J.Geoph.Res.98, 12609)* after a slight modification.

SOURCES AND SINKS OF TERPENOIDS IN FORESTS: CAMPARISON OF FLUXES MEASURED BY ZERO AIR ENCLOSURES AND BY MICROMETEOROLOGICAL METHODS

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Biogenic emissions of volatile organic compounds play a key role in atmospheric chemistry and ozone formation. In the frame of the BEMA-project on "Biogenic Emissions in the Mediterranean Area" we realized that very fast reacting terpenoids are among the most abundant compounds emitted from some ecosystems. We estimated the diurnal course of potential emission fluxes with six zero air enclosure systems installed on representative branches and on the soil. The real terpenoid fluxes above the canopy were analyzed simultaneously with relaxed eddy accumulation and gradient measurements from a tower. In case of a forest dominated by Umbrella pine (t-β–ocimene, linalool), and of a Citrus orchard during (linalool) as well as outside the flowering period (β-caryophyllene) only a few percent of the major compounds emitted could be observed as a flux above the canopy. The soil represented a major source of limonene in both ecosystems. Fluxes of more stable compounds like α–pinene or limonene indicated agreement of the three measuring techniques to within 25% and a promising suitability of our method to develope a general sink function, describing the within canopy removal of reactive terpenoids due to chemical transformation and/or deposition. Completing the budget would require strong efforts in analyzing the within canopy transport, chemistry and deposition, and the formation of reaction products like organic aerosols.

STUDY OF THE ROLE OF BIOGENIC EMISSIONS THROUGH 2-D PHOTOCHEMICAL NUMERICAL SIMULATIONS

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In the general battle against air pollution, a fundamental question is to know whether a reduction of VOC or NOx emissions is the more adequate to reduce ozone concentrations. The term VOC encompasses biogenic (BVOC) and anthropogenic (AVOC) compounds and it is known that the biogenic fraction may be a significant contributor to ozone production/destruction processes due to its high reactivity. By neglecting BVOC, previous investigators may have overestimated the effectiveness of ozone abatement strategies based on reducing AVOC emissions. In the present work, this important problem is studied via numerical simulations by using a coupled mesoscale meteo-photochemical model (TVM-LCC). TVM-LCC is a nonhydrostatic incompressible mesoscale model written in vorticity, including prognostic equations for 35 species involved in 120 gas-phase chemical reactions. An idealised coastal geography representative of the Mediterranean area is selected to produce bidimensional emission scenarios. Those scenarios are designed to quantify the relative importance of various factors that may potentially affect ozone formation: strength and type of emissions, influence of the relative location of anthropogenic and biogenic emission sources, time and duration of these emissions,... For those various cases, the impact of biogenic emissions is investigated over the whole planetary boundary layer.

MEASUREMENTS OF VOC-EMISSIONS FROM AGRICULTURALLY USED PLANTS IN GERMANY

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Plant emissions are thought to contribute substantially to the VOC budget in the troposphere. Up to now only few emission studies have been performed on agriculturally used plants in central Europe.
In spring and summer of the year 1995 we investigated the emissions of C_5-C_{15} hydrocarbons and C_4-C_{12} oxygenated volatile organic compounds (VOC) from wheat, rye, barley, potatoes, maize, rape, and sunflowers on farm-land in Germany. For these studies we used a mobile plant enclosure system with clean air supply. In order to avoid stress effects during the experiments CO_2 and temperature levels inside the chamber were adjusted to the ambient values. The relative humidity in the chamber was kept below 65% all the time. Air samples were collected on adsorption tubes and analysed in the laboratory using a GC-MS/FID-System.
Blossoming sunflowers showed emissions of up to 12.5 μg/h*g (dry weight) α-pinene and 9 μg/h*g sabinene on hot and sunny days. These values are on the upper end of the VOC-emissions from plants reported in the literature so far. In contrast to the light and temperature dependence of plant emissions reported in the literature, the emission rates reached their diurnal maxima several hours before the temperature and radiation maxima were reached. For all other investigated species and substances the emission rates were close to the experimental detection limit (<50 ng/h*g for most compounds) or not measureable at all. Thus they were on the lower end of previous measurements and estimations.

A New Mechanism for Regional Atmospheric Chemistry Modeling

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We will present a new atmospheric chemical mechanism for the modeling of regional air pollution, the "Regional Atmospheric Chemistry Mechanism" (RACM). Ozone is produced through the photo-oxidation of nitrogen oxides and volatile organic compounds including important biogenic emissions like isoprene and terpenes. Since the organic chemistry of the atmosphere is very complicated and computer resources are limited, the RACM mechanism uses grouped organic classes to describe atmospheric organic chemistry. The individual emitted organic species are aggregated into the 31 RACM classes through a reactivity weighting approach. The organic chemistry of the RACM mechanism is a significant improvement over existing mechanisms. The oxidation schemes of alkanes, alkenes and aromatics were reevaluated and improved through the use of new laboratory data. Biogenic species explicitely handled in RACM are isoprene, alpha-pinene and d-limonene. The new isoprene scheme includes an improved representation of methacrolein, isoprene ozonolysis, hydroperoxide production and the carbonitrate production. The peroxyacetyl nitrate chemistry and the organic peroxy radical - peroxy radical reactions were revised which caused a significant reduction in predicted PAN concentrations. The new RACM mechanism has been tested against smog chamber data. Predicted ozone profiles and the timing of the ozone peak are well within the uncertainties of experiments.

DIFFERENCES IN THE OZONE PRODUCTION CAUSED BY TWO ISPOPRENE SCHEMES

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Many studies have shown the importance of biogenic emissions concerning ozone production. In order to quantify the portion of the biogenic emissions, it is necessary to know the horizontal distribution of landuse, temperature and photosynthetic active radiation in detail. The chemical reactions of the species emitted by plants have to be treated with sufficient accuracy to quantify the contribution of the biogenic emissions on photochemical ozone production. With the comprehensive mesoscale model system KAMM/DRAIS the biogenic emissions are determined for a summer smog episode occuring in the upper Rhine valley. The implemented chemistry code RADM2 was improved with the isoprene chemistry of Zimmermann and Poppe (1996). Model simulations with a one-dimensional version and the comprehensive threedimensional modellsystem show the influence of the different isoprene schemes on the ozone production. The results show that the differences between the various reaction schemes depend on the concentration levels.

OA30/ST15 Changes of UV-B radiation in the atmosphere

Convener: Krüger, B.C.
Co-Convener: Röth, E.-P.

OBSERVATIONS OF CHANGES OF THE TOTAL OZONE CONTENT AND SOLAR UV-B RADIATION IN THE ATMOSPHERE OVER UKRAINE

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The changes of the total ozone content (TOC) and solar UV-B radiation (UVBR) in the atmosphere are of great scientific interest due to its vital importance for elaboration of the justified recommendations toward the environmental protection of the biosphere and human health. The regular TOC and UVBR observations were begun in Ukraine since 1973 and continue now at 6 ozonometric and 3 actinometric stations that are equipped by Guschin's filter apparatus covering a territory at sites with latitudes from 450N to 510N. The rich experimental material (more 10.000 sets) and comprehensive theoretical analysis of long-term series of measurements allowed us to realize a procedure of extracting of statistically significant information: detection of seasonal and latitude variations, allocation of annual motion, influence of solar activity, estimation of linear and nonlinear trends. On this base we have found an original method to recover the UVBR field using the TOC, ground albedo and claudiness data. We have developed also a universal computer technique of construction of the distribution of daily dozes of the UVBR flux (irradiance) for any region of Earth's surface using the meteorological satellite pictures. As Ukraine already has own regional ozonometric network, one can provide a good basis for creation a real-time monitoring system to measure and map the TOC and UVBR data that will have a potential to be connected with the European network.

EFFECTS OF CLOUDS ON GLOBAL AND DIFFUSE SPECTRAL UV IRRADIANCE

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The transmission of clouds for solar radiation is nearly independent on wavelength. However, the effect of clouds on global irradiance differs for different wavelengths, because the contribution of diffuse and direct components to global irradiance depends on wavelength. Therefore global UVB irradiance is less reduced by the same situation of cloudiness than global UVA and visible irradiance. This wavelength-dependent effect was experimentally investigated by simultaneous measurements of spectra of global and diffuse irradiance for the wavelength range of 290 to 400 nm during a campaign in June 1996 in Manchester (UK) under conditions with fast varying cloudiness. Additionally, the attenuation of the direct beam by clouds was recorded continuously by a silicium detector with a teflon diffuser which was shielded from the sun every second by a rotating shadow band. The percentage attenuation of the direct beam was about the same for the broad-band silicium detector and for the individual wavelengths of the spectrum. The coverage of the sun by clouds was much more significant for the effects of clouds on global irradiance than the amount of coverage of the total sky by clouds. Finally, a parameterization of the attenuation of global spectral irradiance based on the data of the relatively simple rotating shadow band only is calculated.

INVESTIGATION OF PROPAGATION OF UV-B RADIATION IN THE EARTH'S ATMOSPHERE WITH TAKING INTO ACCOUNT OF ATMOSPHERIC AEROSOLS

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As it is known, atmospheric aerosols play an important role in radiation transfer in the earth's atmosphere. Their importance significantly grows up at consideration of UV-B radiation. This work is one of the steps on the way of investigation of the problem of UV-B radiation propagation in the Earth's atmosphere with taking into account effects of multiple scattering by the atmospheric aerosols. As the initial equations in these sort of problems the general equations of multiple scattering - the Dayson's equation for the averaged amplitude of electromagnetic field and the Bethe-Salpeter' equation for the correlation function of the electromagnetic field, are used. Unfortunately, the analytical solution of these equations has not been found yet. In our case we use suggested by Molyneux approach, which allows to pass to the solving simplified differential equation but with keeping multiplicity of scattering process.
Using this equation for radiation transfer problem together with using of the model of spatial distribution of atmospheric aerosol particles we numerically investigated the laws of propagation of electromagnetic radiation in the aerosol contained media. The comparison of the obtained results with results received from the single scattering model shows, that the cases then the difference between them is significant are not so rare for UV-B radiation. So in most cases it is necessary to take into account the multiple scattering effects.

SURFACE UV FLUX IN JERUSALEM - MODEL AND MEASUREMENTS

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Total UV flux between 290 - 385 nm wavelength was measured in Jerusalem since 1988 by an Eppley UV radiometer. The results indicated a positive trend in the total flux.
In order to evaluate the changes in both UV-A and UV-B, a one-dimmensional numerical model was constructed to compute the surface UV-flux as a function of wavelength, total columnar ozone , solar zenith angle and aerosols. (Other parameters can be introduced if necessary). In order to facilitate comparison of model results with measurements, hourly flux values were computed and total UV, UV-B and UV-A fluxes were obtained. Total columnar ozone values were available, thus model values could be tested by measured ones. The agreement was rather good. Furthermore, an attempt was made to partition the measured UV flux into UV-A and UV-B, by using model results. The variations of the UV-B part of the total UV flux were well correlated with ozone changes.

SOLAR UV-B VALUES IN TWO LOCATIONS IN SPAIN

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Manuel Bañón (Instituto Nacional de Meteorologia)

Daily and hourly values of solar UV-B radiation (320-295nm) for Madrid (655 mts above sea level and located in the center of the country) and Murcia (43 mts above sea level and about 50 km from the Mediterranean coast) are presented.Measurements have been performed with two Brewer Mark IV spectrometers and they cover a period of 3 years (1994-1996) in Madrid and 18 months (mid 1995- 1996) in Murcia*.The main descriptive statistics as well as the time series parameters for both places will be presented.
The relationship with daily total ozone measurements (obtained with the same devices) is also investigated for both locations.
* Quality and checking procedures will be described.

ESTIMATION EUV AND ITS VARIATIONS CONNECTED WITH SOLAR ROTATION ON THE BASE OF IONOSPHERIC OBSERVATIONS

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A few methods of indirect EUV estimation were proposed on the base of ground measurements in the past. The well-known method EUV estimation with help of F10.7-index is good only for meaning estimation. When we compared EUV(F10.7) and EUV(satellite data) for period November, 1979 - August, 1980 result was not so good: the difference between relative variations was up 50%. We realized an estimation of EUV variations on the base of every day data of parameters E-layer ionosphere. It gives us possibility for controlling of changes EUV on the small interval about a few period of solar rotations. The next questions will be discussed: 1) Is it possible to know before hand - what period of estimation EUV on the base F10.7 is not correct? 2) Is it possible to use another methods of estimation EUV in these periods? 3) Our method of EUV estimation with help ionospheric data may it be more good that F10.7 method in these periods? 4) Why F10.7-index is not so good and which structure and dynamics processes on the Sun are caused for this? 5) If there is total information about the different types of variations of EUV and Far UV including solar rotation and QBO of solar activity it is possible to develop a physical hypothesis about QBO-event in the Earth atmosphere?

ANALYSES OF THE POWER RADIATION AMPLIFICATION FACTOR (RAF) BASED ON THE BREWER DATA TAKEN AT BELSK, POLAND, 1993-1996

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Daily doses of the erythemal solar ultraviolet radiation (SUVR) reaching the ground at Belsk, Poland ($52°N, 21°E$) measured by the Brewer spectrophotometer No. 64 during 1993-1996 in conjunction with daily total ozone and integrated global solar radiation are examined to infer their associations under all sky conditions. The observed doses are normalized using daily doses obtained from a parametric model (modified Bird and Riordan model). A multiple regression model is fitted to the erythemal SUVR fractional deviations. The model explains about 95% of the variance in the normalized SUVR doses. The regression coefficients of this model define so-called power RAF. The estimates of RAF are significantly different from 1. This supports the hypothesis that the linear RAF coefficient is not valid to calculate the SUVR response to large changes in the ozone forcing factors (relative to their reference values). In view of the model's results it seems possible that daily doses of the erythemal SUVR at ground level are less sensitive to the ozone changes during overcast days than those during cloudless days.

ALTITUDE DEPENDENCE OF UV-RADIATION

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UV radiation increases with altitude level in the atmosphere, due to decreasing amount of air molecules, ozone, aerosols and of clouds above the relevant surface. This effect is known from measurements and modelling. Besides the parameters mentioned above, in the altitude dependence of UV radiation also variations of surface albedo and elevated horizon are included. The altitude effect depends on wavelength, on receiver geometry and is different for elevated surface and the same altitude level in the free atmosphere. These effects are systematically analysed by numerical modelling. Realistic combinations of the parameters depending on altitude are taken into account. Parameterizations of the UV dependency on altitude are given, which is relevant for radiation estimates e.g. for the UV-Index.

ABOUT THE SEASONAL VARIABILITY OF UV-B SOLAR RADIATION OBSERVED ON THE WEST BLACK SEA COAST

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In case of a relatively constant ozone concentration in the atmosphere , the UV-B radiation reaching the Earth surface at the resort Albena, situated on the Bulgarian North-Wast Black sea coast, is determined mainly by the clouds and amount of atmospheric aerosols. Ultraviolet radiation in the band "B" (UV-B) from the sun affects biosphere and plays an important role in the atmospheric chemistry. The aim of the present study is to describe statistically the relationships between the temporally meteorological parameters (relatively humidity, clouds base & thickness, aerosol contents, etc.) and the corresponding measured magnitudes of the ultraviolet radiation in order to be performed a short-term prediction of the behaviour of UV-B. The method of data analysis includes standard statistical procedures and multiregressional linear models on the base of the least-square fitting equations. From the performed investigation it can be argued that the correlation coefficients are the highest when the meteorological parameters exceed some "critical" magnitudes , assuming that the ozone maintains constantly its contents in the atmosphere .

PRODUCTION RATE OF OH AT AN ISLAND AND A SUBURBAN SITE IN GREECE DURING THE 1996 PAUR CAMPAIGN

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During the 1996 PAUR campaign, concurrent ground measurements of O3, J(O[1D]), humidity and C4-C12 hydrocarbons have been performed at two sites in Greece during the period 1.-15.6.96. The measurements allowed for the calculation of OH production rates as well as relative destruction rates for the OH reaction with various hydrocarbons. The conditions during the experiment were typical for the etesian wind period, with high N-NE winds, good vertical mixing, high ozone values with low diurnal amplitude and high relative humidity. Due to the relatively high ozone and humidity values, production rates of OH were high during the period of the measurements. Concurrent total ozone and aerosol optical depth measurements as well as model simulations are used to derive information on the factors controlling J(O[1D]) and hence OH production in the troposphere.

EFFECTS OF THE TOTAL OZONE COLUMN ON TROPOSPHERIC CHEMISTRY.

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Changes of the atmospheric total ozone column by more than 10 % can happen on a day to day basis due to the atmospheric circulation as well as on a long term due to the general reduction of stratospheric ozone. Photochemical model calculations, both in three dimensions and in a box, have been performed in order to investigate the effect of a changing total ozone column on the tropospheric chemistry. A real episode of three days in September 1994 in the Athens area was chosen as an example and different assumptions for the total ozone column were made. The results show, that a reduction from 320 DU to 270 DU and the subsequent increase of the UV radiation leads to an increase of radical formation and photochemical activity in the troposphere. In the lowest layer of the model the ozone concentration increased throughout the model domain. The box model calculations showed, that only under very clean atmospheric conditions increasing radiation can lead to a reduction of tropospheric ozone.

THE SURFACE UV-EXPOSURE TREND IN THE NORTHERN HEMISPHERE MIDLATITUDES; ANALYSES OF THE 7 VERSION TOMS DATA

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Observed trends in the UV-exposure can result from the long-term changes in the amount of stratospheric and tropospheric ozone and the cloud/aerosol properties. The new version 7 TOMS total ozone and the UV reflectivity data for the period October 1978-April 1993 over the Northern Hemisphere (NH) midlatitudes ($40°N - 55°N$) are used to examine the response of the surface UV-exposure to changes in total ozone and cloud/aerosol properties. The statistical analysis of the relation between total ozone and the UV reflectivity for selected sites (corresponding to the Dobson stations) over this region shows that the UV reflectivity and total ozone are dependent variables. It seems that they are interrelated because part of their variations would be caused by an unknown yet forcing common for these two variables. This forcing depends on season and exhibits longitudinal variations. For some regions in the NH midlatitudes (e.g. Poland) it is found that the "antropogenic" trend in total ozone is responsible for only small part of the observed long-term changes in the surface UV-exposure (about 30% in the case of the UV changes over Poland). It is possible that, in some the NH midlatitudinal regions, the long-term drift of total ozone and the UV reflectivity due to their "natural" variability are main sources of the observed long-term tendency of the surface UV-exposure.

COMBINATION OF SPECTRAL UV MEASUREMENTS AND RADIATIVE TRANSFER MODELLING

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In order to predict future UV changes and to investigate the influence of parameters like aerosol or clouds on ground level UV irradiance, both spectral measurements and model calculations are required. At the Fraunhofer Institute for Atmospheric Environmental Research at Garmisch-Partenkirchen, Germany (47.48°N, 11.07°E, 730 m a.s.l.) we combine spectroradiometric measurements with the radiative transfer modelling package UVSPEC using a specially developed interface (SDMODEL). On the basis of this methods, we present a systematic comparison between measurements and UVSPEC modelling results. 1200 spectra for cloudless sky, gathered during two years, have been used for this analysis. For the optimum model type – a discrete ordinate model with correction for the sphericity of the Earth – the systematic differences between model and measurement were found to be less than ±6% for wavelengths between 300 and 400 nm and solar zenith angles up to 80°. Two input parameters, total ozone column and aerosol optical depth, the latter parameterized by the Ångström formula, are needed to reach this level of agreement. The evaluated UVSPEC model together with the SDMODEL interface provides an efficient tool for the investigation of the processes that control surface UV irradiance.

A METHOD FOR DERIVING SURFACE UV-B FROM ERS-2/GOME AND NOAA/AVHRR DATA

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A satellite based method for deriving spatial distributions of the UV-B radiation at the surface has been developed. The effects of ozone column amount and cloud optical thickness on UV-B were taken into account by the combined usage of the new European-Space-Agency's GOME (Global-Ozone-Monitoring-Experiment) sensor onboard the European-Research-Satellite-2 (ERS-2) and the NOAA/AVHRR instrument, respectively. As examples for application, horizontal distributions of surface UV-B irradiances have been derived in different selected test sites within Europe which represent clear as well as cloudy conditions. Comparisons of satellite deduced UV-B irradiances to local surface UV-B measurements at Hohenpeissenberg (Southern Germany) have been performed. The accuracy of the method is detailly discussed in view of the uncertainties introduced by the satellite and surface measurements and by the radiative transfer model adopted to create look-up-tables which relate surface UV-B radiation to the relevant surface and atmospheric parameters.

A COMPARISON OF URBAN/RURAL ERYTHEMAL UV IRRADIANCES FOR GÖTEBORG, SWEDEN

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The objectives of the study are to examine possible differences in levels of erythemal ultraviolet irradiance between the urban centre of Göteborg (57.70 N,12.00 E) and a clean island location, North Koster (58.83 N, 11.00 E). Two UV Biometers of Model 501 with an erythemal sensor were used for the comparison.
The following procedure was followed for purposes of the comparison. Firstly cloudless days were selected by examining sunshine duration data for both stations during the summer months (June, July, August). Data for Koster was processed to obtain solar zenith angles for the mid-point of each hourly or half hourly period. Similarly, solar zenith angles were calculated for the mid-point of the 10 minute period at Göteborg. Using these values, and daily total column ozone obtained at Norrköping , a clear sky model was used to normalise the data to mean ozone conditions for the region (348 DU). Data was then grouped into one degree intervals between zenith angles 35 and 55 degrees and averaged for each interval. Ratios (Göteborg/Koster) for every one degree interval were examined and mean statistics were obtained. Mean and median ratios of 0.96 and 0.89 were obtained when comparing 1996 Göteborg data with 1994 and 1995 Koster data. Data for Koster collected in 1996 is currently being examined and some preliminary results will be presented.

A SATELLITE-BASED CLIMATOLOGY OF UV-B IRRADIANCE FOR ANTARCTIC COASTAL REGIONS

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A technique is described to map surface UV-B irradiance (erythemal ultraviolet irradiance) for a section of the Antarctic coast bounded by latitudes 59–69 S; 140–160 E. Daily NOAA/AVHRR images have been acquired for this region over four consecutive austral spring, summer and autumn seasons (November-April) starting in 1990. A model developed by Green et al. (1980) is applied to estimate cloudless erythemal irradiance using ozone estimates from TOMS and surface albedo from NOAA/AVHRR. Cloudy irradiances are estimated as the product of the cloudless irradiance and a cloud transmittance derived from satellite imagery. For clear skies model estimates gave RMS differences (model-measurement) equal to 5.7 % of the mean measured value. For cloudy skies RMS differences gave 13.6 % of the mean for daily totals, and 4.2 % of the mean for monthly averages. Monthly statistics are presented as average monthly cloudless irradiance, average monthly cloudy irradiance, and a "worst case" monthly irradiance. Considerable interannual variability is observed in the "worst case" monthly irradiance. Depletion by clouds is very significant and is larger than interannual variability in ozone depletion. The effect of high surface albedo for snow and ice is also important.

THE INFLUENCE OF CLOUDINESS ON BIOLOGICALLY EFFECTIVE UV-IRRADIANCE

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One of the most important factors influencing the transfer of UV-radiation through the atmosphere is cloudiness. The variability in time and space of this parameter complicates the measurement as well as the modelling, so that the interaction between clouds and solar radiation is poorly understood.
Erythemal weighted UV-irradiance data from a UV-Biometer model 501 from Solar Light Company, Inc. and total solar irradiance data from a Pyranometer were collected. The latter are also used as indicator for cloudiness together with half hourly reports of cloud cover and height. Surface observations of air temperature, pressure, ozone and visibility are also included in this study.
The Comparison of measured and calculated clear sky data (modelled with DISORT and TUV) will be presented, taking different types of clouds into account. The influence of clouds on UV-B on one hand and on total solar irradiance on the other hand will also be shown.

INFLUENCE OF TOTAL OZONE VARIATION ON UV-B (ERYTHEMA) RADIATION. AN ANALYSIS OF UV-BIOMETER MEASUREMENTS AT DAVOS, SWITZERLAND.

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Direct, diffuse and global erythemal UV-B radiation are continuously measured by the Swiss meteorological institute at Davos (1610 m a.s.l) and Payerne (490 m a.s.l.) using UV-Biometers. The measurements of the direct erythemal UV (UV-Biometer instruments) at cloudless sky at Davos were compared with a standard parameterization of the attenuation of the extraterrestrial UV radiation in the atmosphere. Daily average Ångström turbidity coefficients were determined for a whole year data set. They show an annual variation with larger values in summer than in winter so as a large day-to-day variation.The increase of direct UV-B (erythema) for a decrease of 1% of the total ozone amount is also estimated for the responsivity of the UV-Biometer and for the action spectrum of human erythema as defined by the International Lighting Commission (CIE). The values are between 1 and 1.2% (dependent on the zenith angle and on the total ozone amount) for the UV-Biometer and slightly smaller values were found for the CIE action spectrum. The comparison of the diffuse UV-Biometer measurements at Davos with the results of a radiative transfer program is now carried out.

THE INFLUENCE OF CHANGES OF UV-B RADIATION ON TROPOSPHERIC CHEMISTRY

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Solar radiation plays an important role in tropospheric chemistry. It has an impact on the concentration of tropsopheric trace gases because it influences photolysis rates and thereby the production of radicals. The effect of declining stratospheric ozone on tropospheric trace gases can be examined by model studies.
Model results of the influence of changes of solar radiation are presented. The simulations are realized with a boxmodel, a one-dimensional and a complete three-dimensional version of the comprehensive mesoscale model system KAMM/DRAIS with the implemented RADM2 chemistry. The radiation transfer and the photolysis frequencies are calculated by the photolysis code STAR. The simulations show that the impact of changes in radiation depends on the degree of pollution of the air mass.

SURFACE ULTRA-VIOLET (UV-B) RADIATION AT HIGH ALTITUDES: A MODEL SURVEY

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Abstract: Exposure to solar ultra-violet (UV-B) radiation is expected to increase with altitude. Over the recent years, there has been a great concern about the increased UV-B and its biological effects at high altitudes (e.g., *Blumthaler et al*, 1993). Large increases in UV reported from high altitudes in Europe and South America support this fact. Measurements of the spectral UV irradiances require precise spectroradiometers with high resolution and stability which are normally expensive. In the UV-B, the altitude effect is mainly determined by the differences in: air pressure, ozone, surface albedo, aerosol concentration, and atmospheric temperature. Using the Discrete Ordinate Method (DOM), a sophisticated radiative transfer model with high spectral resolution, the sensitivity of direct, diffuse, and total (direct+diffuse) UV irradiances to changes in altitude (up to 4 km) and solar zenith angle is investigated. The altitude effect is also examined in the presence of different type of tropospheric aerosols (urban/industrial, continental, soot, soot-sulphate, and maritime). A linear altitude-UV correlation was found for the integrated UV-B (280-320 nm) and UV-A (320-400 nm) and for the erythema, cataract and keratitis biological weighting fractions. This can be applied to interpolate the biological UV-B irradiances at different heights.

THE ROLE OF TROPOSPHERIC OZONE IN FILTERING ULTRA-VIOLET (UV-B) RADIATION

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Abstract: Increases in tropospheric ozone due to human activities may compensate, to some extent, the increased UV-B (280-320 nm) resulting from stratospheric ozone depletion. Using a sophisticated radiative transfer method, the disproportionate role of tropospheric ozone against UV-B, suggested by *Bruhl and Crutzen* (1989), is investigated for various atmospheric conditions. The model results show that at low solar zenith angles, each 1 Dobson Unit (DU) increase in tropospheric ozone can offset the increased in erythemally-weighted UV caused by 2 DU depletion in stratosphere if a typical cloud is present. Clouds tend to elevate the effectiveness of the tropospheric ozone substantially by increasing the pathlength of the photons in the troposphere. Further, the effectiveness of tropospheric ozone in the presence of various aerosols will be discussed. The second area of research is concerned with the effect of vertical distribution of ozone on UV-B. It is demonstrated that for a fixed solar zenith angle, the effectiveness of the tropospheric ozone for filtering the biological UV radiation is mainly dependent on the height of the perturbed ozone layer relative to the scatterers. The role of changes in surface albedo in this issue is also discussed. Increasing albedo tends to enhance surface irradiances; the model results also suggest that the higher surface albedos make the tropospheric ozone more effective at UV-B wavelengths. Finally, a new index is introduced which indicates the change in tropospheric constituents which is required to offset the increased UV-B, following an ozone depletion in the stratosphere.

FREETEX '96 - PEROXY RADICAL MEASUREMENTS AT THE HIGH - ALPINE RESEARCH SITE AT JUNGFRAUJOCH (3,580 m asl) IN THE SWISS ALPS

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Peroxy radicals are of major importance for the ozone chemistry in the troposphere. Such measurements can be used to determine the relative contribution of UV radiation. NO_x and VOC for the in-situ production of ozone. Peroxy radical concentrations (HO_2 + RO_2). and the photolysis rate constants $J(O^1D)$ and $J(NO_2)$. have been measured continuously during April and May 1996 at Jungfraujoch. The method used was a chemical amplification technique and two associated radiometers. It was found that the relation between peroxy radical concentrations and the $J(O^1D)$ photolysis rate can provide an indication on whether or not the atmosphere is clean or semi-polluted. A good correlation between peroxy radicals and the square root of $J(O^1D)$ indicates clean free tropospheric air. whereas a good correlation between peroxy radicals and $J(O^1D)$ indicates semi-polluted air. These relations have been extracted theoretically by steady state approximations. Some example days of the FREETEX '96 campaign with interesting features are presented and discussed in relation to the photochemical theory on the formation of tropospheric ozone.

AEROSOL EFFECTS ON UV-RADIATION: CONSEQUENCES ON BIOLOGICAL PROCESSES AND PHOTOC HEMISTRY

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The variability in UV-radiation due to varying aerosol is estimated by using an accurate matrix-operator radiative transfer model, and biological (eg. DNA-damage, skin cancer) and photochemical (photolysis frequencies of ozone and nitrogen dioxide) effects are evaluated. The variability of atmospheric aerosols is usually described by the variability of aerosol optical depth. However, other properties of the aerosol, besides the optical depth, as spectral course of aerosol optical properties, phase function, single scattering albedo, and aerosol height distribution influence the UV-radiation. All these variabilities within an adequate natural range are modeled with respect to the UV-radiation. The discussion of the results is focussed on the biological and chemical effects of the aerosol variability compared to ozone variations, as well as the resulting problems for modeling UV-radiation due to uncertainties in the aerosol description for an actual case, with and without known aerosol optical depth. A comparison between model results and measurements under different aerosol conditions is presented.

POSSIBILITY OF SPECTRALLY SELECTIVE UV-B DOSIMETRY BY AN *IN VITRO* MODEL OF PREVITAMIN D PHOTOSYNTHESIS

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Amount of solar UV-B radiation (280-315 nm) reaching the earth surface is dependent on many natural factors. Furthermore, ozone layer depletion implies increased intensity of the short wavelength UV-B radiation whereas air pollution hinders its penetration in the biosphere. In view of the fact that bioactivity of solar UV radiation rises steeply as the wavelength decreases, special care must be used to detect precisely both integral UV-B radiation and its spectral distribution.
Vitamin D synthesis in mammal skin is biologically important beneficial effect of solar UV-B radiation. Since the action spectrum peaks at 280 nm dropping to zero at 315 nm, photosynthesis of previtamin D is highly sensitive to the spectral composition of the short wavelength sunlight.
Additionally, profound wavelength effect on the photoisomer formation was revealed using tunable laser initiation [1]. Mathematical modeling and computer simulations of the photoreaction kinetics have provided support that "Vitamin D" dosimeter has an advantage over the majority of biodosimeters making possible not only integral UV-B radiation measurement but also its spectral distribution within 280-315 nm [2].

ACCURACY OF THE DETERMINATION OF SURFACE CLEAR SKY UV IRRADIANCE AT AN ALPINE SITE USING ONLY COLUMN OZONE DATA .

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Routine measurements of spectral UV irradiance and column ozone have been performed at Sonnblick Observatory (3106 m altitude) since Summer 1995 and summer 1993 respectively. These set of data are used to analyze the relationship between surface UV irradiance and column ozone.
Firstly we select the days with clear sky for the following investigations. For all the selected data we use disort model by Stamnes et al.to calculate the surface UV irradiance at 305 and 315 nm using as model input an average aerosol optical depth and an average surface albedo for all the data points. We look at the average relative deviations between calculations and data. After these first comparisons we investigate whether by taking other constant values of aerosol optical depth and of surface albedo we may achieve a better agreement between measurements and calculations.
We secondly analyze the daily fluctuations of the surface UV levels and their agreement with column ozone changes. Finally an estimation of the accuracy of the determination of surface UV using only column ozone is assessed, and the contribution of surface albedo and aerosols on UV fluctuations is estimated.

OA31/ST1 Review session on solar terrestrial relations

Convener: Fabian, P.

VALIDATION OF A FILTER INSTRUMENT FOR UV MONITORING.

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The potentialities of a four channel UV filter radiometer (GUV 511C, Biospherical Instruments Inc.) for the monitoring of UV radiation have been investigated by comparing it (a) with radiometric measurements in Uccle and during two comparison campaigns (Greece '96, Hungary '96) and (b) with modeling simulations. The four channels are respectively centred on 305, 320, 340 and 380 nm. In Uccle the GUV is compared with spectroradiometers, a OL754 (Optronics) and modified HD10 (Jobin Yvon) and with YES pyranometers. During campaigns the GUV was compared to a MKIII double Brewer, a DM150 Bentham spectroradiometer and a UV-B pyranometer. The spectroradiometers are helpful to assess individual characteristics of each GUV channel whereas the broadband instruments ensure, even in bad atmospheric conditions, a comparison between high time sampling rate data. A satisfactory agreement with both the spectroradiometer and the pyranometer was found. Moreover it is obvious by comparing with simulations that the information available from the GUV are more potent than the one provided by the less sophisticate pyranometers and because of their sampling rate around the minute, complementary to spectroradiometer measurements. As an example it is possible to evaluate the atmospheric ozone variability both during the day and or long term scale from the GUV data. Preliminary comparison with ozone determinations provided by the met. office in Uccle (IRM) from Brewer and Dobson instruments will be also presented.

Field Experiment Determination Of Aerosol Radiative Properties And Effects In The Ultraviolet-B Region

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J.S. Schafer (Hughes STX Corp., NASA/GSFC, Greenbelt, Maryland)
J.J. DeLuisi (SRRB, NOAA, Boulder, Colorado)
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A field experiment was conducted in western North Carolina to investigate the relationship between aerosol optical properties and atmospheric transmission. Two research sites in close horizontal proximity but at different altitudes enabled measurements of the transmission of UV radiation through a 1 km slab of atmosphere. An identical set of radiation sensing instruments, including a broadband UV-B radiometer, a direct sun pyrheliometer, and a shadowband radiometer, were placed at both sites. Aerosol size distributions were also measured at the lower site. Broadband optical depth and aerosol optical depths at 415 nm, 500 nm, and 673 nm were measured for the 1 km slab. These measurements along with broadband UV-B transmissions exhibited variations based on air mass source region. UV-B transmission was negatively correlated with both broadband optical depth and aerosol optical depth. Empirical relations were developed to allow prediction of solar noon UV-B transmission if either broadband optical depth or aerosol optical depth at two visible wavelengths (415 nm and 500 nm) is known. A new method was developed for determining aerosol optical properties from the radiation and aerosol size distribution measurements. The aerosol single scatter albedo ranged from 0.75 - 0.93 and the asymmetry factor ranged from 0.63 - 0.76 at 312 nm.

THE ROLE OF THE IONOSPHERE IN THE CHAIN OF SOLAR TERRESTRIAL RELATIONS

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The energy flow of solar electromagnetic and particle radiation through the ionosphere is considered. Examples are explained how the energy (in case of particles also their momentum) is transferred to the thermosphere and the middle atmosphere by various processes. Effects of the variability of the solar radiation are also discussed as well als ionospheric forcing from below which is ultimately also caused by solar irradience.
Our present understanding of the relevant processes is summarized and open questions are addressed.

OA32/NP1.3 Scaling, fractals and nonlinearity in oceans and atmosphere

Convener: Schmitt, F.
Co-Conveners: Cahalan, R.F.; Falkovich, G.; Yanovsky, V.V.

LABORATORY OBSERVATIONS OF CLOUD-CLEAR AIR MIXING: ANISOTROPY IN SMALL SCALES

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A cloud-clear air mixing at scales from 1 mm to 1m is observed in a laboratory chamber. Cloud consists of droplets with realistic size spectra (maximum diameter about 14mm) produced with the ultrasonic droplet generator. Cross-sections through the volume in which mixing takes place are obtained by laser sheet technique (l=0.488mm, thickness of the sheet is 1.2 mm). Light is scattered by cloud droplets and observed at a 90 degree angle with use of video camera. A complicated filaments created during mixing even in absence of external sources of turbulence are observed. Both horizontal and vertical cuts are investigated. Results indicate that at the scale of about 2 cm the nature of the interface separating cloud from clear air changes: at larger it exhibits self similar properties, while at the smaller scales it has a simple geometrical structure. In both range of scales an interface is anisotropic. Below 2 cm the anisotropy is purely geometrical, while above 2 cm there is anisotropy in box counting dimension.

Organisation of geomagnetic field structures during magnetic storms

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The transmitted processes in the Earth's magnetic field are investigated by fractal analysis method of time series. It is found that years time series of magnetic field variations with the hour discretisation interval have Hausdorf's dimension equal to 4. When magnetic storms influence is not taking into account the analogeous time series have approximately dimension 8-10. It is shown that magnetic storm leads to dynamic chaos with finite Hausdorf's dimension. The comparision of data on simultaneous measurement of cosmic rays and magnetic fields variations was carried out. One can suppose that registred magnetic field variations take place at ionospheric heights.

DAY BY DAY VARIATIONS OF METEOLOGICAL PARAMETERS AT THE RUSSIA TERRITORY

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We investigate the temporal scaling properties of two the most popular meteorological parameters: temperature (average daily T, greatest T during the day and minimum T in the day) and precipitation on the timescales from days to decades. Examined series are the data of natural observations which have done at the more than 200 meteo-stations in the Russia territory during the last 100 years. We compare the temporal behavior of these characteristics with the closely connected natural data. All longtime series of natural data are unique; we use a wide set of different techniques to analyse data and to examine their temporal scaling, fractal and nonlinear properties. Specifically we have used wavelet transform which allow us to investigate time-scale behavior and to give a diagnosis for intermittence - a characteristic of turbulent phenomena. For example, at the scales from about 3 years to several decades the time-scale behavior of average daily T is almost regular and is very closely to time-scale behavior of Jones's serie of average annual temperature for the Northen hemisphere. At the scales from days up to about 2 years we have find the weak intermittent behavior. So there are at any rate two different time-scale regimes in temporal behavior of averal daily temperature.

STATISTICAL DISTRIBUTIONS OF CLOUD PARAMETERS OVER EUROPE

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Frequency distributions of ice and water content, sizes and top temperatures have been estimated from a European data base.
The cumulated frequency plots have been well fitted with lognormal and Weibull profiles, the latter of which can be thought of as an approximation of K-distributions describing more realistically the underlying physical processes. According to the shape of cumulated frequency graphs, two or three classes could be found out. This may lead to new criteria for the automatic classification of clouds.

MESOSCALE CLOUD PATTERNS OVER THE EQUATORIAL PACIFIC OCEAN AS INFERRED FROM FRACTAL BOX-COUNTING DIMENSIONS.

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Fractal box-counting dimensions D(0,2) and D(0,3) are computed for satellite infrared images during the TOGA-COARE experiment. Mesoscale convective cloud scenes are defined according to a classification based on VIS and IR clustering technique. D(0,2) is obtained by counting squares of varying size which intercept convective clouds in the images. D(0,3) is computed using cubes instead squares, considering that the counts in the images are related to height. Besides the fractal analysis, we have used the same VIS and IR technique to define cloud clusters and convective cells embedded inside them. Cloud systems are followed during their life cycle using the technique of area overlapping. Meanwhile, several parameters are computed as size, number of internal cells, excentricity, inclination, minimum temperature, among others, including D(0,2) and D(0,3). It is shown that these dimensions vary with the increase of cloud pixels fraction (Ac), number of cells, spatial clustering and isotropy of Ac. These properties were investigated through Principal Components analysis for 352 satellite images over tropical continental areas and tested over the Equatorial Pacific Ocean for the TOGA-COARE data set. It is shown that the box-dimensions D(0,2) and D(0,3) are a useful tool to classify mesoscale cloud patterns in images.

ESTIMATION AND SIMULATION OF SOLAR ABSORPTION IN FRACTAL CLOUDS

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It is now well-known that inhomogeneous clouds reflect less solar radiation than uniform clouds having the same liquid water. However, the proportion of transmitted and absorbed solar is less well understood. There have recently been renewed claims that much more solar radiation is absorbed in the presence of clouds than plane-parallel theory would allow. If true, such absorption has the potential to weaken convective processes as modelled in current climate models, and perhaps even change the sensitivity of models to climate change. With two different analysis techniques, we estimate the column absorption using data from broadband visible and near-infrared radiometers deployed by F. Valero during dual aircraft flights as part of the DoE ARM/UAV (Department of Energy Atmospheric Radiation Measurement and Unmanned Aerospace Vehicle) program. To interpret these estimates, we computed fluxes in a water vapor absorption band (0.9 - 1.0 um) by Monte Carlo techniques for both stratiform ("flat") and convective ("bumpy") fractal clouds generated by a cascade process, tuned to reproduce scaling properties of FIRE and ASTEX observations. Our simulations show that estimates of absorption which ignore horizontal transports will produce values of the -apparent- column absorption greater than the -actual- absorption. However, this bias may be removed by carefully positioning the two aircraft, and by sufficient spatial averaging. For high solar elevations, the -actual- column absorption in the water vapor band is found to be less than that for uniform clouds. Thus cloud structure tends to exacerbate the disagreement between recent observational claims and radiative transfer theory. Future experiments will hopefully provide some direct measure of the horizontal fluxes, which are crucial to a complete understanding of column absorption.

CLOUD GEOMETRY EFFECTS ON RADIATIVE TRANSFER CALCULATIONS

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Radiative codes use simple geometrical shapes, such as parallelepipeds, cylinders... to describe real clouds whereas the shape of natural clouds is highly complex and varies over a wide range of scales.
Shadowing effects may be very important for several solar elevations. So the complex geometry of clouds has been discretized with various scales and radiative transfer calculations have been made with 1D and multi-dimensional radiative codes. Radiation fields have been evaluated for each space discretizations (several tens of meters to 1 kilometer). Albedoes and radiative quantities have been calculated to determine the variations of these values, produced by the scale used to describe the cloud shape.

MULTIFRACTAL ANALYSIS OF OCEAN MIXED LAYER NEAR THE NORWEGIAN COAST

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The nonlinear features of ocean mixed layer is investigated by the multifractal analysis on a thermistor chain data set collected in the Norwegian Current system in October 1989. The data set provides a two-dimensional temperature field from the surface to 250 m depth with 2 m resolution in vertical and 1.85 m resolution in horizontal, and shows high levels of variability excited over a large range of scales by the combined actions of external forcing and internal instability. The stationarity and intermittency are also discussed.

APPLICATIONS OF MULTIFRACTALS IN MARINE SCIENCES

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All oceanographic time/distance series have been shown to exhibit multifractal characteristics: temperature, oxygen, salinity, transmission, pH, light intensity, and nutrients. In addition, biological fields such as fluorescence and ocean colour (surrogates for chlorophyll-a), and zooplankton biomass collected by both ADCP (acoustic doppler current profiler) and OPC (optical plankton counter) are multifractal. In spite of the widespread occurence of multifractal fields in the oceans, most investigations continue to ignore the effects of scale.

The Coastal Heterogeneity and Scaling Experiments (CHASE) is an attempt to incorporate the concept of scale and measurement into the study of marine ecology. The main problem with this approach is the lack of tools to deal with the problem of scale dependency. Multifractal analysis may well be the tool of choice for oceanographers and marine scientists. This paper will outline the various characters of the multifractal marine fields investigated and provide some recommendations for researchers investigating multifractal distributions.

A MODEL FOR MULTIFRACTALITY AND INTERMITTENCY IN TURBULENCE

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The fundamental problem for isotropic turbulence is to understand the statistics of velocity increments $v_r(x) = u(x+r) - u(x)$ on different length scales r. Traditionally either the scaling of the n-th moments $< (v_r(x))^n >$ or the probability density functions $P_r(v_r)$ are investigated. The scaling of the n-th moments leads to multiaffine scaling indices which are set into the context of multifractality respectively intermittency. Here we present a new method of analysing this statistics. We present experimental evidence that the statistics of v_r obeys a Markovian process. We show how Kramers-Moyal coefficients can be evaluated from experimental data. Clear evidence is presented, that the statistics of fluctuating quantities in turbulence can be characterized by a Fokker-Planck equation, i.e. by only the first two Kramers-Moyal coefficients, namely, the drift and the diffusion term. Our approach shows how a distinct multiplicative noise acting on the turbulent cascade gives rise to multifractality respectively intermittency. Finally, we show that the basic process for the complicated statistics of the velocity increments is given by a simple Ornstein-Uhlenbeck process in the logarithm of the energy. We emphasize that this statistical analysis for turbulence can be taken as a new method to analyse fractals.

ON THE REALITY OF THE ESTIMATION OF THE LYAPUNOV EXPONENTS FOR THE ATMOSPHERE FROM THE METEOROLOGICAL TIME SERIES

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The problem of the predictability of the atmosphere belongs to the most important issues in meteorology. The methods developed on the chaos and nonlinear system theory allow to draw out some information on the structure of the attractor from the empirical data. As parameters as attractor dimension, Lyapunov exponents, and Kolmogorov entropy were investigated. In this work the Wolf algorithm for the estimation of the largest Lyapunov exponent (λ_{max}) was applied to the time series of the mean daily values of temperature, atmospheric pressure and water vapor pressure. The data from 9 Polish station were used. Tests with different algorithm parameters were provided as well with original data as with the reference set of random values. Similar to the random data, for the mean daily values of meteorological elements, λ_{max} strongly depends on the algorithm parameters, especially on the *time evolution*. In the light of received results daily values of meteorological parameters provide too rare reconstruction of the weather attractor for real estimation of the Lyapunov spectrum and the Kolmogorov entropy.

INTERACTION BETWEEN VORTEX STRUCTURES IN THIN LAYERS OF FLUIDS

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Among various methods of vortex generation and studies of transient modes of different nature, the particular place is given to the rechnique suggested by the authors, that is a simulation technique in presence of the MHD-effect in thin layers of aqueous electrolytes. This technique allows to generate mass force distribution of any possible form by varying gradient of induction, flow depth and electric current density. It may be considered as the premises for studying the hydrodynamic nonstability, secondary currents, auto-oscillation modes of vorticity. The suggested technique allows to observe nonstable and periodic currents of different types, e.g. A.N.Kolmogorov currents or various auto-oscillations in four-vortices structures. Generation of auto-oscillation has been shown as a result of direct impact of two upward flows. Study of nonlinear hydrodynamic processes in thin layers of fluids using the proposed technique is actual in various technical and natural spheres. This method has been applied to geophysical hydrodynamics in the Institute of Atmosphere Physics (A.M.Obuchov, 1983). It may be helpful for simulation and study of the nature of ocean vortex. By essence, thin layer of fluid may be considered as a classical model in various applications of this theory to meteorology and geophysics.

WAVELET CORRELATIONS IN CASCADING TURBULENCE

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Spatial correlation functions of multiplicative cascade models (p-model, alpha-model) describing the energy dissipation process in fully developed turbulence are calculated with a generating function technique. The structure of the spatial correlation functions simplifies tremendously once the wavelet transformation is used: the covariance matrix diagonalizes and higher order wavelet correlations are compressed to interscale cluster-correlations, which are very sensitive to the cascade dynamics. Moreover, based on adaptive spatial correlation functions, generalisations of the multifractal formalism are found, which very clearly show the shortcomings of the conventional approach.

NONLINEAR INTERDECADAL OSCILLATIONS IN SIMPLE OCEAN MODELS WITH FIXED SURFACE FLUXES

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We have applied a hierarchy of simple nonlinear ocean models to investigate the recently reported occurrence of interdecadal oscillations of the thermohaline circulation under fixed surface flux conditions. Firstly, we have modified a simple box model with fixed "surface" fluxes to allow for a prescribed phase lag between the "overturning" and the north-south temperature "gradient". In that case, the model exhibits interdecadal oscillations, however, these oscillations were damped. Secondly, we have used a somewhat "deformed" non-inertial loop model (by replacing one segment of the loop by a flat horizontal part) which was forced by the loop equivalent of fixed surface fluxes. With such a geometrical deformation the loop model produces self-sustained interdecadal oscillations. In this model the breaking of the circular symmetry causes a phase lag between the overturning circulation and the north-south temperature gradient. Lastly, we have investigated interdecadal oscillations in a geostrophic three-level ocean basin model. Our experiments with this model have shown that a self-sustained oscillation (and a phase lag) is associated with a slow-down of the propagation of cold anomalies in the northwestern corner of the model domain due to an anomalously large area of deep convection in that region. Thus, our experiments support the results of Winton that fixed flux variability in three-dimensional models is not a "meridional plane phenomenon".

CHARACTERIZATION OF ATMOSPHERIC QUANTITIES IN TERMS OF SELF-AFFINITY

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Processes involved in the climate evolution and climate change are among a wide variety of natural phenomena that exhibit self-affine properties. Their identification and reliable characterization through the respective atmospheric quantities can contribute to the better understanding of the fundamental processes governing the climate change. A proper description of the fractal behaviour of atmospheric quantities is provided by a stochastic process with inverse power law spectra. Results from autocovariance function analysis of experimentally recorded time series of water vapor content and liquid water content will be presented and discussed. The analysis is focused on the self-affinity exhibited in a wide but finite range of temporal scales [1,2]. We also discuss a specific effect that is predicted to occur when waves encounter fractal and fractal-like surfaces [3,4]. This effect, which we call diversification of the angular patterns of waves scattered by fractals, if confirmed experimentally, would provide a scheme to measure both the fractal dimension and the important parameter topothesy, characterizing the surface.

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MUTUAL ACTION OF FREE AND INDUCED CONVECTIONS: NUMERICAL STUDIES AND MULTIFRACTAL ANALYSIS

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The results of numerical studies of flow and heat exchange processes in the boundary layer under mutual action of free and induced convections on a continuous non-isothermal surface vertically moving in an immobile external medium will be presented. We proceed to a comparison with experimental data estimating the universal multifractal exponents determining the infinite hierarchy of singularities of the temperature and velocity fields, their corresponding codimensions. The obtained results, within statistical errors, are equal to those obtained in mid-latitude boundary layers.

ON MULTIFRACTALITY OF RAIN RATE AND RADON CONCENTRATION IN THE ATMOSPHERIC SURFACE LAYER

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We apply traditional and modern techniques to the long year data base of synchronous measurements of standard hydrometeorological varaibles, as well as the data on Radon concentration in the surface layer. Firstly, by means of traditional methods it was found high correlation between fluctuations of surface preesure and Radon emission from soil. It also well correlates with the data on X-ray Solar emission (from GOES satellite) with pronounced peaks on periods 14-16 and 28-30 days, which points on influence of solar effects. Also exists high correlation with dayly rain rate. Next, both main processes were subjected to multifractal analysis, and universal multifractal indices were determined. For rain-fall data we again confirmed its mutifractal behavior and universal exponents reasonably correspond to those obtained by Ladoy, Schmitt et al.,1993. Multifractality of Radon data was shown for the first time. PDF of Radon concentration is of hyperbolic type with critical order of high moments divergence about 4. Other indices are: singularity of the mean process ~ 0.15 and Levy index ~ 1.9. Construction of the data-base was partialy supported by grant INTAS-93-1194.

NUMERICAL SIMULATION OF LARGE-SCALE VORTICES GENERATION UNDER CONVECTION IN A SPIRAL TURBULENT MEDIA

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This work is concerned with a numerical investigation of the mathematical model developed at the Space Research Institute of the Russian Academy of Sciences. The model describes the helical mechanism of large-scale structure generation at turbulent convection. This effect acts under condition, when the reflecting symmetry of the small-scale turbulence is disturbed. By using the finite difference method we performed a numerical integration of nonlinear equations of convection with a prescribed external force creating the helical turbulence. It is shown that due to helical turbulence a convective motion picture is qualitatively changed: a single large-scale vortex is generated instead of a large number of small convective cells. We traced the development of different types of initial perturbations. Consideration is also given to time variation of the integral characteristics of motion, in particular, the energy and helicity by changing the constitutive parameters of the problem, initial perturbations, and boundary conditions. The numerical simulation results verified our conclusions, which have been made under laboratory modeling of externally specified small-scale helicity influence on large-scale spiral vortex evolution. This work is supported by RFFI under Grant N 95-01-01094a.

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MEASUREMANTS OF VELOCITY AND PRESSURE STATISTICS IN TURBULENCE

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We present highly resolved measurements of the pressure and velocity fluctuations in different turbulent experiments and different Reynolds numbers. The experimental data are analysed with respect to their statistical properties. We show that both quantities show typical intermittency effects leading to multifractal scaling behavoir of the increments. Probability density functions of the velocity and the pressure increments on different length scales are evaluated. The changing forms of these probability density functions are parametrized. The functional dependencies of the pressure statistics with the velocity statistics are investigated and compared with results from simple dimensional arguments and more recent analytic calculations (R.J. Hill, J.M. Wilczak: J. Fluid. Mech. 296, 247 (1995)).

Analysis and Simulation of Turbulent Processes Using Vector Multifractals

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D. Schertzer (L. M. D., BP 99, Université Pierre et Marie Curie, 4 Place Jussieu F-75252 Paris Cedex 05, France)

Turbulent atmospheric processes can be modelled by energy cascades from large to small scales. Existing cascade models are multiplicative corresponding to the addition of logarithmic generators. Continuous (in scale) simulations are positive scalar since they are based on exponentiating real generators. There is a need to extend this model to describe signed scalars, or more generally vector and tensor fields. This can be done by exponentiation of matrices with the appropriate Lie algebra. However, in general these matrices do not commute and this poses new difficulties. We present some early investigations of such 'Lie Cascades' using commuting basis matrices for simulation. These, in themselves, display a broad range of behaviour corresponding to the coupling of two multifractal processes. Parallel with this work is the (inverse) problem of analysis to uncover these correlations. The most direct analysis is of the generator matrices themselves, but real data is vectorial. Various new methods for vector analysis have been tested on the simulations and are reported here.

MULTIFRACTAL ESTIMATE ON RANDOM FRACTAL NETWORKS

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In this work we present the first tests of multifractal interpolating techniques on random fractal networks, corresponding to a situation commonly found in geophysics and environmental pollution monitoring. The fields considered correspond to lognormal Multifractals. These fields are then sampled by means of random fractal networks. Based on such a sparse information, we try to estimate the fields in the gaps of the networks. Finally comparisons with the whole data are shown, and also with the results provided by more standard interpolating techniques.

THE HETEROGENEITY OF CLOUDS AND THEIR INFLUENCE ON THEIR RADIATIVE PROPERTIES.

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The radiative fluxes through clouds and cloud systems are very much affected by the inhomogeneity in microphysical and morphological characteristics of clouds as well as by their spatial distribution. The idea that the bulk optical properties such as albedo or transmission of inhomogeneous clouds might be dealt as equivalent optical properties of plane parallel clouds at some averaging scale seems to be supported to some degree both theoretically and experimentally by some recent works. Few study has been reported until now about the effect of cloud inhomogeneity on the bidirectional reflectance which is needed for the retrieval of various cloud properties such as effective particle size. The present study is devoted to investigate how the area-averaged radiance field of inhomogeneous clouds can be affected by cloud inhomogeneity and at what scale an inhomogeneous cloud can be treated as plane-parallel cloud. The radiative transfer is simulated with Monte Carlo method for inhomogeneous clouds which are generated with different stochastic cloud models.

INFINITELY DIVISIBLE CASCADE MODELS IN PASSIVE SCALAR TURBULENCE

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We consider here the scaling infinitely divisible models which have been proposed for turbulence (e.g. log-normal, log-Lévy and log-Poisson) for passive scalar fluctuations. The most common way to discriminate between these models is to estimate the scaling moment function $\zeta(q)$ defined as $<(\delta\theta_l)^q> \approx l^{\zeta_\theta(q)}$. We perform this analysis using wavelets to study the fluctuations of the temperature field at each scale. The data we use are atmospheric data (20 m from the ground) taken at 10 Hz with a sonic anemometer. We show first that both log-Lévy and log-Poisson models can give good fits to the scaling moment function for one realization. Then, varying the number of samples studied, we show that a fundamental hypothesis of the log-Poisson model is not respected: the maximum singularity should be already reached for one sample. Other specific techniques (such as a wavelet version of Double Trace Moment Technique) are used to show that the log-Poisson model is not adequate.

FRACTALS AND CHAOS OF THE ATMOSPHERE MOTION NEAR THE MESOPAUSE REVEALED BY VHF RADAR OBSERVATION

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Many observations has revealed the complex motions of the atmosphere due to the nonlinear processes. But there wasn't any reports on the fractal or chaotic features of higher atmosphere such as the mesosphere. During the MAC/SINE campaign in summer 1987,the mobile SOUSY VHF Radar on Norwegian island Andϕya(69^{0}N,16^{0}E) has been used for continuous observations of VHF radar echoes and dynamical processes in the polar mesopause region. We construct the time series by using the horizontal velocity $V_H = (u, v)$ at 86.7km to study the fractals near the mesophere. We calculted the Lyapunov exponent. correlation dimension and entropy of the above time series. As the Lyapunov exponents and entropies are all postive, the atmospheric motion near mesopause are chaotic and have a chaotic attractor. The fractal dimension of the attractor is about 9.44, which is much greater than that in the stratosphere. In fact. since stronger turbulence may be generated from the critical level and saturation level near the mesopause which formed by the interactions between the ambient atmospheric wind and the gravity waves, the atmopheric motion near mesopause becomes more complex than that in stratosphere which was revealed by MU radar. That is consistant with our conclution obtained from the higher fractal dimensions of mesopause.

OA33/NP2.1 Predictability

Convener: Allen, M.R.
Co-Convener: Davey, M.K.

ANALYSIS AND SIMULATION OF VISIBLE RADIATION FIELDS FROM ANISOTROPIC MULTIFRACTAL CLOUDS

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The unified scaling model of the atmosphere predicts large scaling variability associated with fractal structures and multifractal statitistics. To test this, we analyzed several hundred of satellite images of cloud radiance fields using data from LANDSAT, SPOT, NOAA-12 and NOAA-14 (AVHRR), GMS-5, and GOES-6 satellites. The scalig was remarkably well respected even on individual images. The the universal multifractal parameters of the cloud radiance fields over the range of scales of 20m to 5x10^{6}m. We also studied the effects of radiative transfer in anisotropic multifractal clouds using Generalized Scale Invariance. Radiative transfer calculations are performed on such fields using Monte Carlo techniques. The effect of various solar angles, mean optical thicknesses and degrees of stratification are studied.

VARIATIONAL PRINCIPLE AND UNIVERSAL MULTIFRACTALS

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Among broad class of multifractals that of universal multifractals has been selected early. The nature of universal multifractals is connected to the stable distribution laws. The selection of these distributions is due to limit theorems concerning distributions of sums of independent stochastic quantities. In present report another reason for universal multifractal selection is considered. It is shown that this class of multifractals is the most simple form variational principles point of view. Such principle is formulated. It is shown that the extremum ones is achieved at scaling function of universal multifractals. In the framework of the variational principle suggested simplest generalizations of the universal multifractals are proposed. In addition generalized minimum principle determining statistical moments of the universal multifractals is discussed.

DYNAMICO-STOCHASTIC MODEL FOR OCEAN MONITORING — QUESTIONS OF THE ACCURACY AND COST OF COMPUTATIONS.

V. A. Benzhitsky (Marine Hydrophysical Institute Ukrainian National Academy of Sciences, 2, Kapitanskaya St., Sevastopol 335000, Crimea)

Computer monitoring of the real ocean variability is one of the challenging problems of applied oceanography. The most developed approach to its solution is represented by four-dimensional data analysis using dynamico-stochastic modelling of the oceanic. Recently, essential progress has been made in dynamico-stochastic modelling of oceanic density fields that allows the dynamics of density and current velocity fields to be simulated using hydrologic survey data. The more complex the model, the bette the accuracy of ocean dynamics simulation. On the other hand, sophisticated models require larger computational effort, thereby essentially raising the cost of data processing. In this report compared two dynamico-stochastic models with different hydrodynamic parts (complexed amd supplified). As a performance criterion, RMS errors reconstruction are used. It has been shown that in some cases it seems rational to use dynamico-stochastic model with simplified hydrodynamic part. This helps to expedite the computations and reduce the related costs without much deriment to the quality of hydrophysical field simulation. Therefore, depending on the goal of monitoring, a certain compromise is possible between accuracy of ocean field reconstruction by computers and cost of the computations.

ANALYSIS AND FORECASTING OF SHORT-TERM VARIATIONS OF WIND VELOCITY BY AUTOREGRESSIVE MODEL

N.V.Berdunov, A.N.Fahrutdinova, I.S.Nugmanov

We consider application of autoressive method to obtain spectral density of wind velocity series and use AR-model as model of forecasting. Estimation of spectral density of prevailing circulation at the mesosphere-thermosphere region and height dependence of short term variations is presented. Linear prediction model was developed by estimated autoregression coefficient. Criteria s are found in two dimentional time-height correlation function restored series. Results of modeling for various season of year is presented.

PREDICTABILITY STUDIES USING SINGULAR VECTORS

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Singular vectors (SVs) identify perturbations characterized by the fastest growth over a finite time interval (called the optimisation time interval, OTI), with the SVs' growth measured with respect to a metric defined in the linear space of the perturbations. By definition, SVs depend on the OTI and the metric. Moreover, SVs structures can be changed by applying projection operators either in physical or in spectral space. At present, at the European Centre for Medium-Range Weather Forecasts (ECMWF), SVs are operationally computed in two different configurations, both using total energy as initial and final time metrics. The first configuration is characterized by a spectral triangular truncation T42, 31 vertical levels, a 48-hour OTI, and uses a Local Projection Operator (LPO) to confine final time growth to the Northern Hemisphere extra-tropics. The ECMWF Ensemble Prediction System uses SVs computed in such a configuration to generate 50 perturbed initial conditions. The second configuration is characterized by a T63L19 resolution, 24- or 48-hour OTI, and uses the LPO to confine final time growth to a 20 box centred at (10 W,50 N). SVs with these characteristics are used to target adaptive observations. After a brief description of the SVs' technique, examples of SVs' computed in the two configurations will be presented.

PREDICTION OF SUMMER TEMPERATURE IN NW EUROPE FROM PRECEDING WINTER NORTH ATLANTIC SSTA

A. Colman

In 1996, The UK Meteorological Office began making new experimental forecasts of July August Central England Temperature (CET) from January-February Sea Surface Temperature Anomalies (SSTA). THE SSTA are represented by the time coefficients of the first EOF of North Atlantic SSTA. This EOF pattern has positive weights near the east coast of Canada and to the NE of the UK and negative weights south of Greenland and in the Eastern Mediterranean. An SSTA pattern like this is related to warm CET and the opposite SSTA pattern related to cold CET. The Correlation between independent predictions of CET using the SSTA EOF predictor and observed over 1946-1995 was 0.55 which is significant at the 99% level. Temperatures over much of NW Europe are also significantly correlated with the EOF predictor. Historical ocean and atmospheric temperature and pressure fields have been examined to try and explain the mechanism behind this predictability. Possible theories include persistence, advection of anomously warm water across the Atlantic from the East coast of the USA to NW Europe and or variations in amount of snow cover over northern Europe. Evidence supporting these theories will be discussed.

STATISTCAL PROPERTIES OF ATMOSPHERIC LOW FREQUENCY VARIABILITY.

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S. Tibaldi (ADGB - Atmospheric Dynamics Group, Department of Physics, University of Bologna, Viale Berti Pichat 6/2, I-40126, Bologna, Italy)

The predictability of statistical properties of low frequency variability is investigated by studying the dynamical "signal" and the "noise" which arise respectively from the nonlinear response to variations in atmospheric forcing and from the chaotic nature of the atmospheric dynamics. Results from a number of integrations of a realistic simple model provided with different forcings are analysed and compared with the observations.
The attention has been focused in this work on the analysis of the extra-tropical north-hemisphere more relevant pattern of low-frequency variability.

USING TOPEX/POSEIDON ALTIMETER DATA TO ESTIMATE THE UNCERTAINTY OF AN OCEAN MODEL

Michael Chechelnitsky (M.I.T.-W.H.O.I. Joint Program in Oceanography, Cambridge, USA) & Dimitris Menemenlis (M.I.T., USA)

An objective measure of the uncertainty of global ocean circulation models is required for combining model forecasts with data and for making quantitative statements about the general circulation and its interaction with climate, New mail on node LINAX1 from SMTPweather, and other ocean-atmosphere phenomena. The ongoing availability of TOPEX/POSEIDON altimeter data provides the first opportunity to test such models in detail and to quantify their uncertainty which includes effects of stochastic forcing, incorrect model physics, etc. We test several ap proaches for estimating model uncertainty using four years of TOPEX/POSEIDON altimeter data and a reduced-state linear model that describes the large-scale perturbation response of the North Pacific Ocean. Although adaptive Kalman filter algorithms provide a rigorous theoretical framework for estimating model and data uncertainty, we find that these algorithms are not well-suited for the high-order dynamical systems of practical interest to oceanographers. Heuristically-based approaches are less robust but can be computationally simpler and more effective in practice.

DETERMINISTIC CHAOS IN THE ATMOSPHERIC RADON TIME SERIES

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The correlation dimension,Lyapunov exponents and entropy have been calculated for two time series of atmospheric radon isotopes concentrations obtained by four daily measurements during the period 1990-1992. The noninteger values of the correlation dimensions as well as the existence of positive Lyapunov exponents prove that deterministic chaos is present in the atmospheric radon time series. An attempt has been made to correlate the results with the properties of the chaotic attractors in the atmosphere as well as to establish the corresponding equations describing the dynamics of the atmospheric radon concentration. A number of 4200 concentration values of Rn-222 and Rn-220 have been used in the present paper. The measuring method is based on aerosol collection on filters. In order to determine filter activity a low background beta global measuring facility of Nuclear Enterprise type with G-M counter tubes with 2 counts.min-1 background in anti-coincidence was used. The reference standard was S-90/Y-90.

OPTIMIZING PARAMETER ESTIMATION FOR NONLINEAR MODELS

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In most geophysical dynamical systems phenomenological parameters are required, which have to be fitted to measured data. If the data are produced in a laboratory, limited resources (e.g. observation time) rise the question of optimal design and preparation of the experiments.
Parameter estimation is limited by chaotic behavior, stochastic forces and variability of the parameters themselves. The information on parameters given in a (finite) trajectory is hidden solely in the model itself and independent of the methods for parameter estimation . The crucial points are phase space dilatation and sensitivity to parameter variation. We propose two methods to optimize initial conditions and observation times for parameter estimation in nonlinear systems.
In the analytical method one calculates local Ljapunov Expansion Factors as well as linear sensitivities to parameters to combine them in an expression for linear predicted accuracies of the estimated parameters. For systems that are to chaotic, or observation times to long for a proper linearisation, we propose a second method. Therefore we calculate probability distributions on a coarse grained (boxed) phase space. These allow to determine mutual entropies between phase space and parameter distributions.
Both methods are applied to standard examples of chaos theory (like the Lorenz system) and a self made model describing the temporal evolution of bended rivers (meanders).

SEASONAL PREDICTABILITY EXPERIMENTS

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A D L Evans, D S Richardson and M S J Harrison (Meteorological Office, London Road, Bracknell, Berkshire, UK)

The UK Met Office is taking part in a European Union Seasonal Forecast project to investigate potential seasonal predictability for Europe and other parts of the globe. The project involves 2 main stages; an assessment of seasonal predictability gained by running atmosphere-only models over observed SSTs and an evaluation of predictability using coupled models. For the initial 'uncoupled atmosphere' stage of the project GCM integrations are being run at UKMO, ECMWF, Météo-France and EDF. Each centre is producing 9 member ensembles for each season, initialised from 15 years of reanalysis data using the same SST dataset. EDF are only running winter ensembles; the other three centres are producing ensembles for winter, spring, summer and autumn.
Results from the full set of UKMO simulations will be presented. The UKMO integrations have demonstrated statistically significant skill over North America and other parts of the globe. There is evidence of skill over Europe. We hope to improve our seasonal forecasts for Europe using post-processing techniques such as singular value decomposition. UKMO simulations have been combined with results from ECMWF to investigate the benefits of multi-model ensembles on seasonal timescales. We have found evidence that the joint ensemble provides improved information over the individual ensembles.

HOW PREDICTABILITY DEPENDS ON SEASON AND GEOGRAPHICAL LOCATION IN A COUPLED MODEL OF THE EL NINO / SOUTHERN OSCILLATION.

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The predictability of any complex, inhomogenous system generally depends critically on the estimated/prescribed analysis and forecast errors. A simple and efficient singular vector analysis is used to study the predictability of a coupled model for El Nino / Southern Oscilation(ENSO). We investigate how the predictability of the coupled model depends on the geographical location of initial analysis errors, and on the geographical location of accepted forecast errors - the choice of norm. We also investigate seasonal variations in the predictability of the coupled model, addressing in particular the question of whether seasonal variations in the dominant singular value (the "spring predictability barrier") may be related to the strong seasonality in the amplitude of interannual variability.

PREDICTION OF FORECAST UNCERTAINTY: PROBLEMS AND APPROACHES

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Errors in the specification of the initial state of numerical weather prediction models represent one of the major limiting factors on the accuracy of weather forecasts that is achievable when forecasts are made with dynamical models of the atmosphere. In addition to errors in the specification of the initial state of the model, errors in the model formulation itself degrade the quality of forecasts. To treat consistently forecast uncertainty introduced through these two error sources requires to view the atmospheric prediction problem in a probabilistic framework that is provided by the Liouville equation (LE) which describes the time evolution of the probability density function (pdf) of the model state vector. Within the framework of the LE, the problem of predicting the uncertainty of model forecasts can be reduced to the question of time-evolving the initial pdf. The LE will be introduced as starting point for discussing approaches to the prediction of forecast uncertainty, such as stochastic-dynamic prediction, modified Monte Carlo methods, and presently operational ensemble prediction systems. Particular attention will be given to the concept of singular vectors. It will be argued that singular vectors present a most efficient means, under certain assumptions, as their time-evolved counterparts present the eigenfunctions of the covariance structure to be predicted. Results for covariance prediction in simple atmospheric models will be presented. Ways of relaxing assumptions (e.g., the tangent-linear approximation in weakly nonlinear situations) will be briefly discussed.

FLOW DEPENDENT PARAMETRIZATION ON A SIMPLIFIED MODEL

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An extremely simplified model of has been built with the aim of modeling the large scale atmospheric flow. The model used is a Quasi Geostrophic three-level model. A control run has performed making use of a forcing term obtained as an average model residual. Consequently, a flow-depended parametrization is sought, making use of different statistical techniques to establish the relation between flow and model residual. The model climatology and variability improvement and the prediction skill on the seasonal timescale are tested against the different parametrizations chosen.

MODEL OUTPUT STATISTICS APPLIED TO ENSEMBLES OF SEASONAL GCM INTEGRATIONS

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Multivariate statistical methods such as singular value decomposition and canonical correlation analysis are applied to ensembles of GCM simulations and observations and used to identify leading modes of variability on seasonal time scales. It is often the case that the leading model mode shows a pattern which is spatially displaced, due to systematic errors in the model, from the corresponding pattern of the leading mode of observations. However, the same pair of leading modes may show very good temporal agreement which would indicate that the model responds at the correct points in time to external forcing. When this is the case the leading modes can be used to form the basis of a statistical adjustment to the model simulations. The improvement of the accuracy of simulated precipitation for different areas resulting from this kind of model output statistics is tested in cross-validation experiments for an ensemble of three simulations forced with observed SST for the period 1961-94. Examples include (i) Feb-Mar-Apr rainfall in North East Brazil where the raw simulations show a small region of high skill in the central part of the Nordeste region whereas the statistically adjusted simulations show an extended region of equally high skill around the same area, and (ii) simulations of Jan-Feb-Mar precipitation in North America where a modest overall improvement in skill is found after statistical adjustment.

LONG-TERM DEPENDENCE AS A STEPPING STONE FOR PREDICTION OF RAINFALL

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Paleoclimatic results of lake Chad level secular variations during the last Millennium and extrema of the Southern Oscillation since 400 yr have,at a secular scale,the global spectral response of isotops,laminations and thermoluminescence profiles 138-143 yr and 164-168 yr cycles permit to reduce uncertainty as for as a wet Sahel coming-back. The following step is a comparative non-linear extrapolation of modern time series,which are lengthened until 1998,either randomly or deterministically i.e. with 45-55 yr and 75-85 yr recurrences.

SUB- AND INTERANNUAL VARIABILITY OF THE EXTRATROPICAL OCEANS

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We explore the low-frequency variability of the mid-latitude wind-driven circulation numerically and observationally. Three intermediate reduced-gravity models – a shallow-water, a 1-1/2 and a 2-1/2 layer quasi-geostrophic model – are forced by a zonal wind stress, sinusoidal in latitude and constant in time or with a seasonally varying amplitude. For steady forcing, bifurcation studies of the double-gyre circulation that arises reveal the existence of multiple equilibria, as well as periodic and aperiodic solutions, when varying the model ocean's parameters. Two periods dominate the model's internal variability: one is of a few months and the other of a few years; their exact values depend on basin size, boundary conditions, and other parameters. These two oscillatory modes are explored in terms of instability mechanisms, basin- or meso-scale. The model oceans exhibit phase locking when the zonal wind stress is allowed to vary seasonally. Multi-channel singular spectra analysis is applied to extract fundamental features of the model oceans' dynamics and variability. Interactions between the eastward jet and eddies, as well as the role of barotropic and baroclinic components, are investigated. Finally, the results of our simulations are compared with the observed variability of the mid-latitude oceans, in the hope that the former will help predict the latter.

DREAM PERTURBATIONS IN ENSEMBLE FORMATION: INSIGHT THROUGH SHADOWING

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Modern prediction methods make use of ensembles of initial conditions; there are several competing methods of ensemble formation. Ideally, one wishes to include as a member of the ensemble, an initial condition which reflects the future behaviour of the system as accurately as possible, given the imperfections in the model. Define the 'dream perturbation' to the initial observation (or corresponding analysis) as that which yields this initial condition. This initial condition will 'shadow' the future trajectory, yielding the best possible prediction under the given model. We present shadowing as an alternative means of model evaluation, and demonstrate its application to ensemble formation. While the initial state of a physical system can never be known exactly, we show that shadowing provides an indication of the dream perturbation. This facilitates a new means of comparing competing ensemble formation methods. Applications to numerical and laboratory systems are presented, along with implications for NWP models.

PREDICTABILITY OF DECADAL NORTH ATLANTIC CLIMATE FLUCTUATIONS IN A COUPLED OCEAN-ATMOSPHERE GCM

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A interdecadal oscillation of the North Atlantic climate system with a period of approximately 35 years period has been discovered in a multicentury integration with the global coupled GCM ECHAM3/LSG. The simulated decadal mode relies on a feedback loop which involves both the oceanic thermohaline circulation and the atmosphere over the North Atlantic region.

The existence of such a decadal oscillation in nature would imply the possibility for making climate predictions in the extratropics on decadal timescales. A series of ensemble forecast experiments starting from perturbed initial conditions have been performed to study the predictability of the models North Atlantic climate system. It will be shown that the ocean's interior is predictable up to 20 years. Nevertheless, the climate of the model's atmosphere is much less predictable. Its predictability is limited to a few years.

CHAOTIC HAMILTONIAN SYSTEMS AND DATA ASSIMILATION BY PERIODIC UPDATINGD

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An example of conservative Hamiltonian system is presented where in order for the forward assimilation by sequential, periodic, updating to achieve a better convergence, the observed data should not be updated with the highest possible frequency. This turns out to be true for cases where the conserved quantity (Hamiltonian) is unconstrained or constrained during the assimilation process. In particular, in the former case the correct energy can be reconstsructed at the end of the process. When the energy is constrained the assimilation converges, generally, to the right trajectory but stays slightly away from it through (non random) noise effect with a more rapid convergence for lower updating frequencies. The optimum choice of the assimilating frequency is also addressed.

A FASTEX ANALOGUE IN THE LORENZ 95 MODEL

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Modern prediction methods for spatiotemporal systems are increasingly able to identify structure in each particular initial condition that will grow to produce large uncertainty in the forecast. Once regions of particular interest are determined, observation programs can be developed with the ability to selectively gather data in these areas. Such dynamic observation systems provide a novel means of constraining uncertainty growth over the forecast period. The FASTEX (Fronts and Atlantic Storm Track Experiment) project has been initiated by the US government to provide a means for Numerical Weather Prediction (NWP) scientists to obtain measurements over data-sparse areas of the Atlantic Ocean in an effort to improve weather prediction. The challenge is to develop a method for selecting optimum regions to observe in order to increase prediction skill. An analogous experiment, using both 4DVAR and simple replacement as the assimilation scheme, considers the Lorenz 95 model within the FASTEX framework. Results from breeding vector, singular vector and lyapunov vector orientations in determining the region at initial time that contributes most to forecast error at final time are presented. Extensions to GFD experiments and implications for FASTEX itself are discussed.

ON SPECTRAL GAPS AND PREDICTABILITY OF CLIMATE

Andreas Hauschild (Institute of Physics (Meteorology, Humboldt-Univ. Berlin and Meteorological Institute (Theoretical Meteorology), FU Berlin)

The reproducible experiment is a consisitency test, almost independent of theor y. The impossibility of conducting experiments on the global system has direct c onsequences for predictability. A methodology is called for which does not requi re experiments to predict unknown states in phase space.
In general, theoretical progress leads to improved predictability without experi ments. The recent development of Nambu representation of hydrodynamic equations represented such a step. The concept of Fluctuation-Dissipation-Relation (FDR) i s also a candid ate for such a methodology.
In order to test the theoretical progress, I analysed Reynolds averaging procedu re of convective transports in different types of hydrodynamic equations. The va rious failures were quantified by data analysis. The quantitative analysis will be shown also o n video in section OA23.
The applicability of FDR will also be discussed. The FDR combines the fluctuatio ns in equilibrium with the response of the perturbed system to an external force . This relation can be taken to handle special events in the climate system like volcanoes, El Nino and others, using them similarly to experiments.
It can be shown, that in all cases analysed, a spectral gap in phase space varia bles is required.

ON PREDICTABILITY OF A NONLINEAR STOCHASTIC DYNAMICS BY DETERMINISTIC MODELS.

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If the behaviour of a nonlinear stochastic system can be described by a Markovian diffusion approximation and that the evolution equations can be reduced to a system of ordinary differential equations analytical formulas for the calculation of prediction time and its dispersion were obtained. In our approach these values depend upon the given accuracy of prediction, the intensity of external turbulence noise, the accuracy of initial conditions, the adequacy a determinate model to the reality, the measurement errors and the number of prediction variables. A numerical application to the Lorentz attractor illustrates developed theory.

USE AND ASSESSMENT OF ENSEMBLES IN THE MEDIUM-RANGE

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33-member medium-range ensembles from ECMWF have been available to scientists at Member States since late 1994. Other meteorological centres are now producing ensembles, and the relative merits of a multi-model approach can now be studied. The control run and the perturbed fields are integrated out to T+240.

Mean fields for days 1-5, 6-10, 4-6 and 7-10 are produced. These are inverted using multiple linear regression equations to produce period-mean forecast anomalies of temperature, precipitation and sunshine covering ten UK areas. This is the method used in the production of UKMO extended-range (30-day) forecasts. Clusters have been calculated and inverted in the same way.

Since forecast assessment is a multi-dimensional problem, several methods of assessment have been used, for control runs, all members, ensemble means, and clusters. For deterministic forecasts, Folland-Painting skills have been used, while probability forecasts are assessed using Ranked Probability Skill Scores. Reliability and Relative Operating Characteristic curves are also used, from which it is seen that the forecasting methods are deficient for near-normal conditions, with most of the skill coming from relatively extreme events. This problem is currently being addressed, with improvements sought in the inversion procedure.

It is shown that, even if the model is uncertain (ensemble shows large spread), probabilistic forecasts still contain some value. With this in mind, application of similar techniques to monthly and seasonal forecasting is briefly discussed.

A TEST FOR SELF-CONSISTENT PREDICTION STRATEGIES

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Predictive models are abundant in geo-physics, ranging from full simulations to statistically based models. Faced with unavoidable uncertainty in an initial condition and error in a prediction, one would like to determine whether the loss of predictability is due to the model or the data. Uncertainty arrises in the observations and evolves under the model; by better understanding of the former, we may more effectively interpret the latter. Ensemble forecasts strive to quantify model sensitivity: large ensemble spread implies low prediction skill. This is a computationally intensive process. Alternatively, we may study the evolution of the observational uncertainty using a linearisation of the model. While this assumes the observational uncertainties are "small" (infinitesimal in fact), it significantly reduces the computational cost. We use a self-consistency checking procedure to identify "bad" regions of state space - those where the prediction error is inconsistent with the expected observational uncertainty and known model sensitivity. By iteratively feeding this information back into the prediction scheme, we attempt to obtain a model which is consistent with both. We contrast this new approach with existing methods of uncertainty prediction. Results for experimental systems are presented, in particular, an experimental analogue of the atmosphere the rotating annulus; an application to field data (wind flow over Ireland) is also discussed.

PROJECTIONS OFF FRACTAL FUNCTIONS: A DETERMINISTIC FRAMEWORK FOR CHAOS AN D STOCHASTICITY

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The construction of a vast class of deterministic measures over the line, define d transforming simple multifractals via fractal interpolating functions, is revi ewed (Puente, 1992). It is shown that by changing the procedure's parameters (those of the fractal in terpolating function and those defining the parent multifractal), measures resem bling nature's (time or space) series may be obtained. Examples having diverse complexity, as defined by power-law power spectra with v ariable exponents β and multifractal spectra (codimension) having alternat ive Levy indices α and entropy dimensions D_1, are given and an analysi s of the possib le dynamical origin of such sets is presented. It is illustrated that usage of nonlinear dynamics tools lead to the conclusion that some of the (deterministic) series could be described as coming from a low- dimensional "chaotic" dynamical system (having less than 5 coordinates), while others, being sensitive to initial conditions but requiring a large number (more than 20) of c oordinates, would be termed "stochastic".
It is argued that the representation used to define the measures, or a similar o ne based on the general concept of projections off fractal functions, may be rel evant to understand whole (positive) complex series deterministically. Implications of the results for prediction purposes are given.

TWO TYPES OF BOUNDARY FORCING AND PREDICTABILITY OF AN AGCM IN ITS MULTIYEAR INTEGRATIONS

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In this work we try to understand long-term predictability of climate by examine the results of three ensembles of multiyear integrations with the NCEP-MRF AGCM. One of the ensemble consists of two sets of 10-year output of the AGCM's integration with a climatological mean annual cycle of global SST. The other two ensembles consist of nine of 142-month integration with the forcing of observed SST for the period of February 1982 to November 1993. The later two ensembles are differ by the use of alternative convective parameterization schemes. Interannual variability of the ensemble average is used to measure sensitivity of the model to the interannual variation of SST forcing. Sample-to-sample variability is used to measure the uncertainty of the model results. Also, a normalized signal-to-noise ratio is introduced to measure predictability of the system. The 200mb wind, precipitation, and vertical velocity are examined. The interannual variability of the ensemble mean shows east-west asymmetry: maximum centers are located in the western part of the tropics (140E-0). The sample-to-sample variability shows north-south asymmetry: the uncertainty is much larger in the mid-latitudes of the Northern Hemisphere. By examining the 200mb divergence, 500mb vertical velocity we notice that large sample-to-sample variabilities are associated with high topography where the uncertainty in precipitation is small. This leads us to infer that the mechanical orography interaction is a mechanism that reduces predictability of AGCM. Our assumption is verified by examining (i) the seasonality of signal versus noise ratio; and (ii) the interannual variability of the AGCM runs with forcing of climatological mean annual cycle of SST. Changes of the convective parameterization scheme can improve the predictability but only when the impact of airflow-orography interaction is not strong.

DETERMINISTIC PREDICTABILITY OF THE ECHAM3/LSG COUPLED MODEL OVER THE ATLANTIC EUROPEAN REGION

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The predictability of the T21 version of the ECHAM3 atmospheric model coupled to the LSG ocean model is investigated. The monthly mean of 500 mb geopotential height anomalies over the area 0° - 90° N; 100° W - 90° E from a 700 year integration of the this coupled model are analysed.
The maps of the highest Lyapunov exponent and Kolmogorov entropy show that the model predictability is higher at low and high latitudes than that of middlatitudes. The predictability tends to be higher over the ocean than over the land. The main patterns emphasised by these maps do not change significantly for various values of the embedding dimension and the delay time.
The dependence of predictability on various time scales of atmospheric processes is also investigated. To this end the atmospheric attractors have been reconstructed from time series smoothed with various running mean filters. The model predictability seems to increase as the averaging period increases

DIAGNOSE AND FORECAST OF THE MODERN TENDENCY IN THE INTERANNUAL FLUCTUATIONS OF THE BALTIC SEA LEVEL

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Analysis of long period changiability of the Baltic Sea level was made. Rise of the sea level during the last 10-15 years and the beginning of its decrease in the early 90-s were determined. The changes of the sign of modern tendency in the sea-level variation occur in different time for different tide- gauge stations. Croscorrelation and crosspectral analysis of the sea level records with the global and regional atmosphere and oceanographic forcing, forming the long period sea level changes allows to reveal the main factors. As a result, a statistical model of the multiple regressions was constructed. This model was used to forecast the tendency in the sea level changes over few years in the future. The result of the test calculations have shown good agreement with the sea- level records.

FOUR-DIMENSIONAL DATA ASSIMILATION AS A TOOL FOR MODEL VALIDATION

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One possibility of validating climate models against observations is by four-dimensional data assimilation (Newtonian relaxation). This method is particularly useful for the validation of physical parameterization schemes in the models or for measuring campaigns where observations are available only for a limited time. Since often no sufficient obervations are available, one is left to analyses, which themselves are model-generated.
Inclusion of a relaxation term into the model physics generally not only affects the parameters directly involved, but also alters the balance between the parameterized and the dynamical quantities. Furthermore, inconsistencies in the model formulation between the analysis and the forecast model as well as errors in the assimilated real data lead to additional differences from the observed state.
An attempt is made to quantify these effects by means of "identical twin" experiments in which the forecast model is forced by its own model generated rather than observed data. This prevents the problems mentioned above and may serve as an important step towards a consistent validation of climate models with real observational data.

SEASONALITY AND REGULARITY OF THE EL NIÑO-SOUTHERN OSCILLATION FROM 1950-96

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The econometric X-11 seasonal adjustment procedure allows for changing seasonal shape, and when applied to the monthly mean Niño-3 Sea Surface Temperature (SST) index gives an annual cycle showing substantial interannual variations. Typically during warm El Niño events, late autumn and winter are warmer whereas spring is cooler than normal, which causes the annual cycle to have a weaker amplitude and a phase advanced by about a month. The spring barrier in ENSO predictability is a natural consequence of such interannual modulations in the annual cycle. However, the relationship failed during the El Niño of 1992/3 which had the largest amplitude annual cycles. A temporal embedding of the deseasonalised trend suggests that the low frequency El Niño phase evolution from 1950-96 is not fully chaotic but is remarkably regular except for anomalous phase variations in 1951/2, 1960/1, 1974/5, and 1992-94.

PREDICTING THE QUASI-REGULAR PHASE OF ENSO IN THE EMBEDDING SPACE $(x, \dot{x})$

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The interannual anomalies of the Niño-3 sea surface temperature index show remarkably regular and monotonic phase evolution when embedded in the space $(x, \dot{x})$, approximated by using a 12 month centered time difference. With the exception of the anomalous periods 1951/2, 1960/1, 1974/5, and 1992-94 when the oscillations occurred about displaced means, the monotonicity of the phase evolution suggests that ENSO is in general a quasi-periodic oscillation and not a truly chaotic system. A simple quasi-periodic model is used to attempt a dynamical systems prediction of the Niño-3 index and the strengths and weaknesses of the method are discussed and compared to results from non-parametric predictions.

PROBABILISTIC WEATHER FORECASTS BASED ON THE NCEP ENSEMBLE

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Due to the chaotic nature of the atmosphere the quality of weather forecasts generally degrades with increasing lead time. The rate at which predictability is lost at different locations and at different times, however, depends a lot on the instability characteristics of the prevailing atmospheric flow. A practical approach to quantifying predictability in a nonlinear forecast situation is to run an ensemble of forecasts from slightly perturbed initial conditions. We found that the initial perturbations can partly account for that part of the model generated error that is random in nature (i. e., truncation errors) and hence projects onto the fastest growing perturbation directions with time. At NCEP, the breeding method is used to generate initial perturbations that are likely fast growing analysis errors. Including the control forecasts, a 17-member ensemble is run every day. This ensemble is then used to derive probabilistic forecasts for different variables. First the 500 hPa height forecasts were evaluated in a systematic manner, using traditional and probabilistic measures. We found that despite the somewhat insufficient spread in the ensemble at later lead times, the equally likely ensemble members can be used to create valuable probabilistic forecasts even for the extended range. In particular, the forecasts can be made almost perfectly reliable by calibrating the forecast probabilities, using verification statistics from a preceding forecast period. Examples of probabilistic forecasts for 24-hour accumulated precipitation will be shown where reliable daily weather predictions could be made even 7–10 days in advance. For up to date ensemble forecasts and other information, see our ensemble web site at: http://sgi62.wwb.noaa.gov:8080/ens/enshome.html.

1. GSC (Laurel, MD) at NCEP

LONG-RANGE CORRELATIONS IN THE ATMOSPHERIC CIRCULATION: ORIGINS AND IMPLICATIONS.

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By considering 500 hPa measurements we demonstrate the existence of scale invariance in the variability of atmospheric circulation anomalies. This scale invariance is associated with positive long-range correlations meaning that if an anomaly of a particular sign exists in the past it will most likely continue to exist in the future. Moreover, this scale invariance indicates that the dynamics of small scales (as small as a week) are connected to the dynamics of large scales (up to a decade) via a simple power law. We trace the origin of this invariance to the existence of hemispheric anomaly fields that change slowly and thus tend to persist. We discuss the implications of this finding in the modeling and prediction of the responses of our climate system.

SEASONAL FORECASTING OF NORTH AMERICAN STATION TEMPERATURES USING SPACE-TIME PRICIPAL COMPONENTS.

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An empirical model using as predictors Sea-Surface Temperatures (SST) filtered through Multi-Channel Singular Spectrum Analysis (MSSA) is applied to the seasonal forecasting of station temperature data over North America (Canada + U.S.). Several versions of the model are proposed; the most successful one consists in a prior prediction of filtered predictors followed by a predictand specification stage. A comparison is performed with recent Canonical Correlation Analysis (CCA) linear forecasts. The former turns out, in this application, to be more skillfull in most seasons. We argue that this is due to the nonseasonal nature of the MSSA and to overfitting problems inherent to CCA. Canada turns out to be the country where skill is most significant; during winter, high skill values are also found over South-Western U.S.

SST-FORCED CLIMATE VARIABILITY IN THE AFRICAN SECTOR DEDUCED FROM ENSEMBLE GCM SIMULATIONS AND OBSERVATIONS

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The ECHAM4 atmospheric general circulation model (GCM) has been integrated at T30 resolution through the period 1960-1994 forced with the observed sea-surface temperatures (SSTs) as complied at the Hadley Center (GISST2.2). Three experiments were made starting from different initial conditions. The large-scale tropical precipitation patterns simulated by the model have been studied, focusing on the skill (i.e. the capability to simulate the observed anomaly over land areas) and reproducibility (i.e. the GCM's interannual rainfall variance that is independent from the initial conditions). Various Singular Value Decomposition Analyses (SVDAs) are performed, between observed and model fields (OM analyses, to study skill) and amongst the different model runs (MM analyses, to study reproducibility). Moderate to good reproducibility is found for all seasons over Africa, and skill for the first SVD mode is good in austral winter and boreal spring. In the GCM in boreal summer, West Africa rainfall correlates with the tropical Atlantic SST in agreement with observations, but West Africa is incorrectly teleconnected to the tropical Pacific, leading to poor overall GCM simulation skill, much less than an empirical simulation from SST using canonical correlation analysis (CCA), which is good even for the sub-decadal timescale. However, using pre-rainfall season SSTs, only the Guinea Coast region shows good CCA forecast skill at sub-decadal timescales, illustrating the need for SST forecasts in the tropical Atlantic and tropical Pacific in summer.

SCALE-VARYING SSA OR DATA ADAPTIVE WAVELETS?

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Multiple regimes of behavior and the transitions between them are ubiquitous in climate dynamics, from atmospheric blocking to the alternation of glacials and interglacials. The corresponding observables of interest are therefore generally nonstationary or intermittent, and hence their variance is ill-defined even if they do not exhibit a trend. This problem can lead to spurious spectral analysis results when stationarity is implicitly assumed.
We extend singular spectrum analysis (SSA) to the study of time series that may exhibit intermittency, relying on ideas from wavelet analysis. SSA that is in scale and time allows to find adaptive functions to decompose a time series, and hence contain the formalism of wavelet transforms, but using an adaptive basis. We present several examples of application to intermittent signals with power-law behavior which mimic the features of "classic" climatic time series.

OA34/NP3.1 Dynamics and transport of active and passive tracers

Convener: Hua, B.L.
Co-Convener: Pasmanter, R.A.

A USING OF RESISTANCE VALUE IN TURBULENT TRANSFER TASKS

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A conception of resistance in turbulent transfer tasks is completly analogous to this one in heat- and electro- technology . A resistance value is a function of every finite layer , normal to flux. It is determined by equation, analogous to Ohm low . The resistance is much more stable value , than turbulent transfer coefficient . It is convinient for using and accessible for determining . For example . it may be easy calculated in a case stationary vertical turbulent transfer in the ocean from radioactive or some another traser profile, even if the profile is very discrete and has a large data error. It is easy to solve a nonstationary task too.

TRACER LAMINATION IN THE STRATOSPHERE - A GLOBAL CLIMATOLOGY

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Vertical soundings of stratospheric ozone often exhibit laminated tracer structures characterized by strong vertical tracer gradients. The change in time of these gradients is used to define a tracer lamination rate. It is shown that this quantity can be calculated by the cross product of the horizontal temperature and horizontal tracer gradients. A climatology based on UARS satellite borne ozone data and on ozone-like pseudo-tracer data is presented. Three stratospheric regions with high lamination rates were found. The part of the stratospheric overworld which is influenced by the polar vortex, the part of the lowermost stratosphere which is influenced by the tropopause and a third region in the subtropical lower stratosphere mainly characterized with strong vertical shear. High lamination rates in the stratospheric overworld were absent during summer, whereas in the lowermost stratosphere high lamination rates were found year round. Several features of the derived climatology are roughly consistent with earlier balloon borne studies.

ON THE ABILITIES OF THE EULERIAN NUMERICAL SCHEMES TO INCORPORATE EMISSION AND DEPOSITION

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Unlike the traditional assessments of the "advection" properties of the schemes (numerical diffusion, mass conservation, etc.), the present study considers a non-investigated side of the schemes - the problem of incorporation of emission and removal processes.

The analytic stationary solution of the one-dimensional Eulerian equation for emission, advection and loss of material is obtained. Cases of different complex space distribution of emitters and regions of sharp mass loss (precipitation) for different values of dry deposition and wind speed are considered. The popular numerical schemes are applied to model the above mentioned cases. The errors of the schemes are between 1% and 80% of the analytic solution, depending on the scheme, the incorporation technique and the modeling situation.

Tables of the analytic solutions for different cases are available. They could serve as a pattern with respect to which different schemes and incorporation techniques could be tested.

THE STRATEOLE EXPERIMENT : A STUDY OF THE SOUTHERN POLAR VORTEX USING ISOPYCNAL BALLOONS

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The aim of the STRATEOLE experiment, planned by the French Space Agency (CNES), is to study the dynamics of the southern polar vortex at the end of the austral winter and at the beginning of spring when it dilutes. The experiment will consist in launching 200 isopycnal balloons at 50 hPa and 70 hPa levels in the stratosphere, near the vortex border. The balloons are designed to survive as passive tracers for at least 3 months and will provide detailed information on their trajectories as well as on physical and chemical parameters. Numerical simulations using high resolution analysis of the stratosphere have been conducted to study the behaviour of such balloons. We will correlate the transport and mixing properties of the flow to the proper behaviour of the polar vortex defined itself from the VP gradient and the stratospheric jet.

Passive Tracers in Oceanic Convection

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In the course of a pilot study for the simulation of carbon-dioxide uptake in the Greenland Sea during active convection passive Lagrangian tracers were introduced to a 2.5-dimensional non-hydrostatic convection model. Model domain is a vertical ocean slice with an isotropic grid size of 10 meters, vanishing gradients normal to the plane, and with cyclic lateral boundary conditions. The horizontal dimension is chosen according to expected convective aspect ratios which vary between 1 and 3. An observed stratification from the Greenland Sea is prescribed as background field. Model forcing for transient momentum and heat fluxes is determined from ECMWF-data. Simulations cover periods in the order of weeks to months. A simple thermo-hydrodynamic sea ice model is interactively coupled to the convection model. Simulations are initialised with an isotropic random distribution of tracers in model domain. A statistical analysis of tracer dynamics will be presented which focuses on predicted contact times of water parcels with the atmosphere as a critical measure for carbon-dioxide uptake. A contact is inhibited if the predicted ice thickness exceeds a critical value.

THE EFFECT OF RECIRCULATIONS ON THE RESIDENCE TIME OF A PASSIVE TRACER IN A SEMI-ENCLOSED BASIN

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In this work we investigate the dispersion of a passive tracer in a semi-enclosed basin. The attention is focussed on the importance of the presence of recirculations inside the basin. The study, performed through a numerical Eulerian model, is carried out in terms of macroscopic descriptors of the behaviour of the system; in particular, in terms of the residence time of the tracer in the basin, suitably defined, and of the principal eigenvalue of the advection-diffusion operator.

Advection and diffusion inside and out of a semi-enclosed basin are first approached by studying a one-dimensional channel.

Thereafter, an analogous process is studied in a two- dimensional semi-enclosed basin, with a flow characterized by the presence of a recirculation in correspondence of the outflow open boundary. It is seen that the presence of this recirculation is at the basis of the main differences between the one- and the two-dimensional cases, which indeed virtually coincide in the case of a 2-d non-recirculating mean flow. In particular, the behaviour of the principal eigenvalue vs the diffusivity coefficient is clearly affected by the mean flow pattern, and this is explained by qualitative and quantitative considerations.

Dynamic of the passive tracers in the turbulent atmosphere: case study for the Transcaucasus.

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Dynamic and transport of the active and passive (natural or artificial) tracers show some particularities for the high relief regions. Hydrodynamic equations were used in order to describe this phenomena. The 2D and 3D models of the passive aerosol cloud distribution in the non-uniform atmosphere is proposed, considering the high relief conditions. The solution is given in spherical coordinates using the method from G. Marchuk. Analysis of rich experimental data allows us to conclude that the horizontal size of the aerosol clouds depend on their internal turbulence parameters. Their "life capacity" however, depend on the external turbulence parameters and to the earth's relief. The proposed models were tested for latitudes between 1000-10000m. The experimental data are in good agreement with the theoretical predictions.

STATISTICAL KINEMATICS OF A GCM

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Transport characteristics of an atmospheric general circulation model have been analysed by computing 30000 trajectories over several months. These trajectories have been used to construct an advection-diffusion operator for the zonally averaged transport of passive tracers. Several different methods have been tried for this purpose. The most promising seems to be a method were eddy-flux statistics for a large number of tracers are generated and used to find a best fit flux-gradient relationship. This represents an extension of the method introduced by Plumb and Mahlman (JAS 1987). The meridional circulation of the advection-diffusion operator is direct almost everywhere, but is very weak outside the tropics. Diffusion coefficients show a quite complicated structure with minima near the jet maxima. The relevance of the advection-diffusion approach has been tested for a number of different tracers, including the potential vorticity. The Stokes drift is shown to be very important for potential vorticity fluxes near the tropopause. Certain limitations of the advection-diffusion model have been identified. In particular there seems to be problems related to Walker cells. The use of a large number of different tracers has also allowed us to improve on the flux-gradient relationship by including higher order terms.

THE OBSERVATIONAL STUDY OF THE NORTH ATLANTIC CURRENT

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In May-June 1990 the r/v "Akademik Kurchatov" made several CTD and XBT sections crossing main hydrophysical fronts on the Newfoundland Energo-Activ zone (45-53N,36-45W) and deployed 14 moorings for approximately one month period at the section along the 36W(47-53N) with current meters at depths of 100, 400, 1000, 2000 and 3500 m. The analysis of these data shows that the North Atlantic Current (NAC) had two branches (Central and Southern) splitting apart near 48N where the 4500 m isobath turns east at approximately right angle to the 4000 m isobath. The Central branch continues going to the north-northwest along the 4000 m isobath, turns east near 51N and crosses the 36W meridian between 51and 52N. The Southern branch of the NAC roughly follows the 4500 m isobath and crosses the 36W meridian near 48N. The mean transport of the Central and Southern branches of the NAC across 36W constitute 62.4 and 48.7 Sv correspondingly. The return westward flows were observed at section at 36W between the Central and Southern branches of the NAC and at the north and south edges of the section with total mean transport of 50.1 Sv. The strong meridional flows were observed at the section at 36W with northward streams to the north of 49N and southward streams to the south of this latitude, where seamount (2600m) was registered in 1990 by the r/v Akademik Kurchatov. All main flows penetrated throughout the water column from 100 to 3500 m. The largest velocities were observed in the upper layers. They decrease at 1000 and 2000m and have a small increase near the bottom.

LAGRANGIAN SPECTRA IN ROSSBY WAVE FIELDS

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We consider the advection of "floats" in an idealized field of Rossby waves. When the wave amplitude is vanishingly small, the Lagrangian spectra collapse to the Eulerian spectra. When the waves are stronger, spectral broadening occurs, with higher and lower frequencies present. The broadening is rationalized kinematically. Generic features of observed spectra for oceanic floats can be reproduced with a superposition of strong waves. Comparisons between constrained and dynamically unconstrained results are made.

LAGRANGIAN MODELLING OF TURBULENT DIFFUSION AND CHAOTIC ADVECTION ACROSS A MEANDERING JET

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Particle exchange in correspondence of meandering jets is a topic which has been extensively studied, since it can shed light on mixing processes taking place across western boundary currents and/or their extensions.
This communication present the results of a kinematic study aimed at determining the relative importance and the joint effect of turbulent diffusion and chaotic advection on the cross-stream mixing.
This is done by looking at simulated Lagrangian data obtained by integrating the trajectory equation for a flow which is composed by two factors: its deterministic portion, resembling a meandering jet with recirculating side cells, is time-dependent and therefore allows for mixing induced by chaotic advection. On top of that, a stochastic velocity field is superimposed, characterized by finite turbulent space and time scales, which has proven to be able to describe upper ocean mesoscale turbulence. Given the relative complexity of the flow, Lagrangian statistics are performed also in non-conventional ways, aimed at discriminating among different transient regimes in the dispersion process.

TURBULENT DIFFUSION AND DEPOSITION OF ATTACHED AND FREE RADON PROGENY OVER VEGETATED SOIL

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The steady-state one-dimensional diffusion equation of radon progeny over a vegetated soil is solved analytically. The K-theory is assumed to be valid both within vegetation canopy and in the open atmosphere. The radon progeny is classified into two groups: attached-to- and unattached-to-aerosol, each being characterized by a particular dry deposition velocity independent of height. The deposition is considered to be effective only within the vegetation layer. The calculated air progeny concentrations and deposition values are compared with measured values.
Some unexpected experimental results, such as an equilibrium factor greater than 1, can be explained by this model.

ANOMALOUS DIFFUSION BY RESONANT TRIADS OF GRAVITY WAVES AND ROSSBY WAVES

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We study a passive scalar advection by resonant triads of gravity waves and Rossby waves, respectively, by integrating Lagrangian equations of particle motion in the plane (a vertical one in the first case and a horizontal one in the second) with velocity field provided by a resonant wave triad. We analyse a large variety of triads and find that for many of them a phenomenon of ballistic advection of the tracer takes place, i.e. while for majority of initial positions of tracer particles a slow diffusion takes place, there are regions of positive measure in the phase-space where tracer particles experience a rapid ballistic motion in a direction determined by internal geometry of a triad. We also study advection properties o f a broad-band spectrum of waves in order to understand how the above-mentioned phenomenon affects the effective diffusion coefficient.

A COMPARISON OF POTENTIAL VORTICITY WITH STREAMLINES IN THE ABYSSAL OCEAN

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and R. G. Williams

Isolines of large-scale potential vorticity, $Q = -f\partial\sigma/\partial z$, on isopycnals represent possible paths of free flow. The Stommel-Arons model of the abyssal circulation assumes a slow, linear flow which does not significantly affect the stratification. variations in Q are therefore controlled by the meridional gradient of f and free meridional flow is blocked by zonal isolines of Q. Flow across isolines of Q requires forcing and in the Stommel-Arons model a polewards interior flow is forced by an upwelling at the top of the abyssal layer.

An earlier study (O'Dwyer and Williams, 1996) showed that the distribution of Q on abyssal isopycnals varies with depth and between basins. There are regions of near-uniform Q and regions where isolines of Q have a meridional component. In this study the NODC climatological dataset is used to calculate geostrophic streamlines with a middepth level of no motion which are compared to the Q field. In contrast to the Stommel-Arons model regions exist where Q isolines are aligned with streamlines, suggesting a more nonlinear dynamical regime where the flow has a significant free component. Therefore, in these regions the simple layer models of free, adiabatic flow that have been formulated to describe the thermocline circulation may be relevant for understanding the dynamics of the abyssal circulation.

AN INVESTIGATION OF A VORTEX STREET BEHIND A HEATED CYLINDER

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Is experimentally shown, that the heating of a cylinder, streamlined by a flow of air, results in a increase of distance of formation vortex to it an d in increase of their intensity. Effect of space growth of a pulsations of temperature in a trace for a heated up cylinder is found out. Theoretical model of a vortex street of a path at a heated up cylinder, enabling to explain these effects is constructed.

ON SOME PROBABILITY CHARACTERISTICS FOR POLLUTANT PARTICLE IN THE AIR

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The analysis of atmosphere state is quite actual geophysical problem because of human activity influence. We study passive pollutant spreading in the atmosphere considering regular (with the wind) and Brownian motion of the particles. The problem is to obtain the probability density for particle's velocities in the fixed space point (detector). We devise some special mathematical method and determine a number of probability distributions such as probability density for the time of arrival to the detector and the velocity at this point.

ESTIMATES OF TURBULENT TRANSPORT FROM LAGRANGIAN DATA.

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Turbulent transport of passive tracers is usually computed from Lagrangian data using an approach based on the concept of eddy-diffusivity. This approach is simple and effective, but it has some strong limitations, since it is based on the assumption that a gap exists between the scales of the turbulent eddy-field and those of the mean field. This is often a questionable assumption in the ocean, especially in strongly inhomogeneous and non-stationary regions, such as the western boundary extensions and the equatorial currents. In this paper, the problem of identifying a robust methodology to compute turbulent transport, valid also for inhomogeneous and-nonstationary flows, is addressed. A new, optimized method (Bauer et al., 1996) to decompose the flow into a mean flow and an eddy-field using Lagrangian data is first summarized. Examples of Lagrangian statistics in various oceanographical flows are then shown, including situations where the eddy-diffusivity concept can be applied, and other situations where the hypothesis of scale separation is not met. For these situations, alternative methods to the eddy-diffusivity approach are indicated and discussed.

LAYERING IN A TURBULENT STRATIFIED FLUID

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Turbulent motions in a stratified fluid cause irreversible mixing, by transporting buoyancy across isopycnal surfaces. If the fluid is weakly stratified, then the turbulence leads to an enhanced, eddy diffusive buoyancy flux. In very stable, high Richardson number regions the character of the flow alters as internal waves are generated, and diapycnal mixing is suppressed. This variation in diapycnal mixing with Richardson number can lead to the intensification of inhomogeneities in the density profile. There is considerable observational and experimental evidence that high Richardson number flows have a generic layered structure. However, the mechanism for the initial formation of layers is not clear.

Experiments have been carried out to investigate layer formation in a linearly stratified fluid through vertically homogeneous stirring. In all experiments, well-mixed layers form adjacent to the top and bottom boundaries of the fluid, where the buoyancy flux must fall to zero. Layers form in the body of the fluid if the Richardson number is sufficiently high. At intermediate Richardson number. layer formation is driven by the divergence of the buoyancy flux due to the presence of horizontal boundaries. The interfaces at the edges of the boundary layers sharpen, and then more mixed layers and interfaces form sequentially in the central portion of the tank. Once formed, the interfaces sharpen according to the tendency of high Richardson number flows.

TEST OF A HIERARCHY OF FINITE VOLUME TRANSPORT SCHEME IN A GENERAL CIRCULATION MODEL

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Among the schemes proposed for advecting atmospheric trace sepcies, finite-volume schemes in which the evolution of the mean mixing ratio inside a mesh is evaluated from an estimation of the flux at its boundaries, presents the advantage of being conservative by nature. Van Leer (1977, J. Comput. Physics, 23:276–299) proposed : 1) a hierarchy of schemes in which the accuracy of the classical first order upstream scheme is improved by introducing successive moments of the tracor distribution, and 2) a way to insure monotonicity (and hence positivity) by moment limitation. Two of those schemes (schemes III and V) were introduced later on in the GCM community by Russel and Lerner (1981, J. Appl. Meteorol., 20:1483-1498) and Prather (1986, J. Geophys. Res., 92:6671–6681). For practical applications however, those schemes present the drawback that the higher order moments can hardly be treated in "physical parametrisations" such as convective mixing or chemistry. As pointed out by Edouard et al. (1996, Nature, 384:444-447), Van Leer scheme I avoids this problem by diagnosing the first moment of the distribution instead of treating it as an independant advected quantity. We present cross-comparisons of these various schemes in the frame of an atmospehric general circulation model, using idealised prescription of sources and sinks but a realistic atmospheric flow. We show that, at a given numerical cost, Van Leer scheme I can do as well or even better than the other schemes by increasing the spatial resolution.

DATA ASSIMILATION FOR OCEAN EDDIES: OBSERVING-SYSTEM DESIGN AND FLUID MIXING ESTIMATION

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Data assimilation helps solve initial-and-boundary value problems for geophysical flow models when initial or boundary data are obtained from incomplete and noisy observations. Estimation of transport and mixing for the solutions of such problems requires estimating the flow field first.
In this study we focus on mid-latitude oceanic eddies that play an important role in heat, mass and momentum fluxes. We assimilate very sparse data to estimate flow dynamics and the associated transports by designing a data-adaptive observing system. To do so, data assimilation methodology and dynamical systems theory are systematically combined. Using the extended Kalman filter of sequential estimation theory, we first demonstrate how subsurface flow information can be extracted efficiently from surface observations. Chaotic mixing techniques are then applied to estimate the flux carried by the eddies and the fluid's mixing with the surrounding flow field.

USE OF THE KALMAN FILTER TO IMPROVE RESULTS OF RECEPTOR-POINT PHOTOCHEMICAL MODELS

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A Kalman filter has been implemented on the Danish Atmospheric Chemistry Forecasting System (DACFOS) which is based on a coupling of the chemical routine of the EMEP MSC-W oxidant model and DMI's 3-D Lagrangian transport model utilizing forecast and analysis data from DMI-HIRLAM, the operational numerical weather-prediction model at DMI. The Kalman filter is used to improve the forecast skill by taking advantage of local surface measurements at the arrival point of the trajectories.
The results of this model complex from 1996 are presented. The experiencies obtained in finding the optimal operational setup is reported. This primarily includes: determining model and measurement error-covariances; effect of sampling frequency and data averaging; performance of a linear Kalman filter versus a heuristic/empirical nonlinear Kalman filter.
The filter is used in one of two ways: Either by starting from uniform initial conditions (of state and error-covariance) a prescribed number of days before the forecast (4 days seems to be adequate) or using conditions obtained from the state at the previous forecast origin – which DACFOS makes every 12 hours. The latter seems the obvious choice for an operational setup, but it does suffer from side effects such as difficulties in recovering from bad forcasts. The former makes the skill of the individual forecasts independent but would present a significant overhead in models with many arrival points.

PASSIVE TRACERS IN HETEROGENEOUS AQUIFERS

Kacimov A.R., Obnosov Yu.V.

New analytic solutions and known results of Muskat and Polubarinova-Kochina are used for particle tracking procedures in porous massifs composed by blocks of different conductivity with rigorous refraction conditions along interfaces. Eulerian (breakthrough curves, effective conductivity, concentration or water table elevation envelopes) and Lagrangian (travel times along path lines, contaminant plumes, reference volume distortion pictures) characteristics are evaluated and computed on the base of explicit expressions of specific discharge vectors. As compared with standard numerical procedures like MODFLOW it allows to avoid numerical differentiation of nodal heads and brings only Runge-Kutta integration errors. The flow pattern near a geological shift (Chapman, 1981) is studied in details. Nontrivial effects of acceleration and retardation of tracer, longitudinal and transversal 'dispersion' are evaluated. For transient regimes analogies with Lagrangian chaos of point vortices follow from the type of sigularity (sink-source) which model extraction-pumping wells and corner points of blocks. Optimization of protection measures with plume size as a criterion and liner conductivity/thicknes as a control function are solved. Dispersion coefficient in 1-D advective dispersion equation is connected with fingering picture in purely advective 2-D pattern.

A NEW MODEL FOR TRANSPORT OF PARTICLES IN BOUNDARY LAYER FLOWS.

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A model for the study of the interaction of the planetary surface with the atmosphere is discussed. Viscous atmospheric flows with any small viscosity remain to be zero on solid boundary in consequence of the no-slip conditions. Our prime interest hear is with the dynamical phenomena attendant on the wind blowing the Mars surface (dust transportation, direct action of atmosphere on surface). With this in mind we abandon the zero conditions for the horizontal velocity in favour of using nonviscous equation. In this case corresponding velocity component near the surface is forecasting value and total wind flow is determined only by zero vertical component boundary conditions. we use the system of univelocity equations of the multy-phase fluid for Martian atmosphere description. This lets us to analyze the structure of wind flows over complex terrain in the important case of nonstationary conditions of dust lifting and dust deposition and predict wind flows in close proximity near the surface.

FORECASTING SURFACE OZONE IN DENMARK

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DMI (Danish Meteorological Institute) has developed an operational forecast system for ozone concentrations in the atmospheric boundary layer. The system is based on the coupling of the chemical routine of the EMEP MSC-W oxidant model and DMI's 3-D Lagrangian transport model that uses forecast data from DMI's numerical weather prediction model DMI-HIRLAM (High Resolution Limited Area Model). The system is called Danish Atmospheric Chemistry FOrecasting System, **DACFOS**.
The system is set up to make 36-hour forecasts automatically twice a day for selected sites or receptor points within the EMEP-grid that covers all of Europe. Ten backwards trajectories (96 hours) arriving at different heights within the atmospheric boundary layer are calculated including the meteorological parameters needed for the chemistry model. For each trajectory the concentrations of the chemical species are calculated independently of the other trajectories.
The analyses of ozone forecasts for Jægersborg in Denmark for two summers '95 and '96 show that the model reproduces many of the observed features quite satisfactorily.

DENSITY COMPENSATED THERMOHALINE FRONTS IN A QUASI-GEOSTROPHIC FLOW

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The process of stirring of large scale temperature and salinity anomalies by oceanic mesoscale turbulence ultimately produce small scale thermohaline fronts with almost no signature on the density field. The prediction of the statistics of these small scale thermohaline fronts help to assess the magnitude and distribution of the salinity and heat fluxes. The numerical results reveal that the largest mixing of thermohaline anomalies can be rationalized in terms of 3-D tracer cascade.

Shear-flow instability in a parabolic vessel

J.A. van de Konijnenberg, A.H. Nielsen, R. de Nijs, J. Juul Rasmussen and B. Stenum

The instability of a forced, circular shear layer in a rotating fluid has been studied experimentally. The experiments were performed with a layer of water in a rotating parabolic vessel. The shape of the vessel corresponds with the curvature of the free surface at the angular velocity of the system, so the water layer has a uniform vertical thickness. By choosing a slightly higher or lower angular velocity, it is also possible to obtain a beta-plane. The shear layer was produced by a secondary rotation of the inner part of the parabolic tank. Above a critical inner rotation speed, the shear layer becomes unstable, and is transformed into a chain of equally-signed vortices. Depending on the experimental parameters, this configuration may be stationary, or perform an oscillatory motion. The number of vortices is found to decrease with increasing strength of the shear. We present measurements of the mode number as a function of the shear strength and dye visualizations of the vortex chains, as well as transport properties of small particles at the surface of the fluid.

ZONAL TRANSPORT CREATED BY ROSSBY WAVES

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Numerical simulations with the kinetic equation for weak geostrophic turbulence on the β-plane have shown that wave-wave interactions mainly support zonal motion components. An experiment in the "Coriolis" rotating tank was performed in order to test this hypothesis. The β-plane was modelled by a 50-qm sloping bottom. An oscillating paddle was used to generate zonally propagating Rossby waves. Their parameters coincide with the predicted values within an accuracy of 5%. A stochastic wave field with a broad spectrum subject to evolve according the kinetic theory is expected to arise owing to reflections of waves as well as owing to non-homogeneities of the bottom and walls. The two-dimensional velocity field within an area of ca 2.5*2m was measured with the CIV method (Fincham 1995). Simultaneously, data from a cluster of ultrasonic sensors were recorded.
In the majority of experiments we observed a noticeable zonal transport in the form of weak jets with a typical width 1m and a typical speed 0.1mm/s in the central area of the sloping bottom. There was no analogical transport near the walls or in the area of the flat bottom. The transport has no vortex-like structure and probably was induced by weakly nonlinear wave-wave interactions.

MODELLING OF LARGE SCALE POLLUTION RESULTING FROM A LEAKAGE OF RADIOACTIVE SUBSTANCES DUMPING ON THE SEA BOTTOM.

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A particle model coupled with 3-D flow Princeton Ocean Model are used for modelling of radioactive pollution transport in the sea bottom layer in case of an accidental leakage of sources dumping on the sea bottom. At forecasting simulations, a special attention is paid to matter transport under condition of turbulence generation by bottom topography and tidal currents. Numerical simulations are performed for Russian Arctic seas.

IMPACT OF INCREASED VERTICAL RESOLUTION ON THE TRANSPORT OF PASSIVE TRACERS IN ECHAM

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A requisite task for understanding the global climate and its change including the atmospheric chemistry is the investigation of stratosphere–troposphere exchange processes. We examine stratosphere–troposphere exchange (STE) globally by employing the atmosphere general circulation model ECHAM4, which is equipped with a semi-Lagrangian tracer transport scheme. However, a well known deficiency of the operational ECHAM4 model is its too strong STE. In order to overcome this shortcoming we increased the vertical resolution of the operational ECHAM4 model. Unlike ECHAM4, which has 19 levels and a mean vertical resolution of 2 km, the modified version, hereafter called ECHAM4.DLR39, has 39 levels in the vertical and a mean resolution of 1 km. It is shown that ECHAM4.DLR39 is able to reproduce the observed climate. Artificial and natural passive tracers have been introduced into ECHAM4 and ECHAM4.DLR39. Their transport characteristics on both small and larger scales are examined and a comparison is presented.

TRANSPORT PROCESSES IN THE STRATOSPHERE AND OZONE VARIATIONS.

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We discuss the mechanisms of transport of chemical species in the stratosphere and across the tropopause, and their role in the variations of ozone concentrati on in the lower stratosphere. In particular, we focuse on the small-scale heterogeneities, on the possibility to reconstruct them from time series of synoptic-scale analysis and on their impact on chemistry, leading to ozone depletion.

ON A TWO-DIMENSIONAL MAP DESCRIBING CONVECTION AS A SIMPLIFICATION OF THE LORENZ EQUATIONS

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The description of processes in as simple as possible terms is one of the goals of science. For this reason an attempt has been made to reduce in a particular limit the three-parameter, 3D Lorenz equations (to some extent describing convection) to a two-parameter, 2D map. The 2D state vector can physically be interpreted as the location of the
centre-of-mass with respect to the geometric centre (see Maas, 1994). As its assets the map contains many of the features known for the Lorenz system: a conductive state that loses stability for increasing heating to two convective states, and a subsequent loss of stability of these convective states, for still higher forcing values, ultimately leading to a chaotic state on a strange attractor. In a few cases the dynamics on an invariant set can be rigorously shown to be chaotic by relating it to a shift map. As an off-set the 2D map also introduces a new "fixed point" at infinity, which naturally leads to a discussion on the domain of attraction of the physically realistic states, as opposed to that of "infinity". The Mandelbrot and Julia sets of the map and their possible relationship to observations will be discussed. (Ref: Maas, L.R.M., A simple model vor the three-dimensional, thermally and wind-driven ocean circulation, Tellus 46A,671-680.)

SELFORGANISATION IN QUASI-2D TURBULENCE: EFFECTS OF BOUNDARIES

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In the last decade, the formation of coherent vortices in decaying 2D turbulence has been studied extensively by numerical simulations. However, most studies concerned 2D turbulence on a double periodic domain. What happens when the fluid is confined to a finite domain? How do viscous boundary layers influence the evolution?

We present an experimental and numerical study of 2D turbulence in a square and a circular container. Experiments are performed in a stably stratified fluid, in which a quasi-turbulent initial state is obtained by global forcing with a 'rake' of vertical cylinders. Numerical simulations on a square domain are based on a 2D Chebyshev pseudo-spectral method. Comparing the situation of no-slip versus stress-free boundary conditions, we will show that the advection of viscously generated wall-vorticity influences the flow evolution dramatically.

Particle trapping in forced shear flow

A.H. Nielsen, J.A. van de Konijnenberg. R. de Nijs, J. Juul Rasmussen and B. Stenum

We have numerically investigated particle trapping by vortices emerging from an unstable circular shear flow. The shear flow was created by solving the forced two-dimensional Navier-Stokes equations in a bounded domain using expansion inChebyshev polynomials in the radial direction, and Fourier decomposition in the azimuthal direction. Passive particles were traced with spectral accuracy. For a weak forcing, a finite number of stable vortices (4-10) emerges in the shear zone, and particles initialized inside the vortices will be trapped. With increasing strength of the shear, the number of vortices will decrease. For a small number of vortices (2-3), oscillations occur inside the vortices and a significant detrapping of particles can be seen. We compare these results with experimental results obtained in a rotating parabolic vessel.

TRACER ADVECTION SCHEMES AND UPTAKE OF CO2 IN A 3-D GLOBAL OCEAN MODEL.

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Advection dominates transport of carbon and others tracers throughout much of the ocean. Advection is implemented in 3-D ocean models. Differences between advection schemes may help explain disparities between model CO2 uptake estimates; however, no studies are available that quantify if such differences are important. We separately use three advection schemes (upstream, centered differences and flux-corrected transport) in otherwise identical simulations focused on ocean uptake of CO2. These schemes are the same as those used by most 3-D ocean modelers within the carbon cycle community. Our first test swith bomb C-14 revealed that relative to the reference scheme (flux-corrected transport), the numerically diffusive upstream scheme results in higher gobal penetration depths (7% more during GEOSECS; 16% more in 1995) and smoothing sharp gradients. The centered difference approach (numerically dispersive) produces negative levels of bomb C14 as well as biases where gradients are most intense. We will discuss how analogous problems are found in anthropogenic CO2.

SIMULATIONS OF COSMIC RAY CROSS FIELD DIFFUSION IN HIGHLY PERTURBED MAGNETIC FIELDS

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The process of particle cross-field diffusion in high amplitude alfvénic turbulence of different forms is considered with the method of the Monte Carlo particle simulations. We derive the cross-field diffusion coefficient $\kappa_\perp$ and and the parallel diffusion coefficient $\kappa_\parallel$ in the presence of different 1-D, 2-D, and 3-D turbulent wave field models and we analyze the variation of $\kappa_\perp$ and $\kappa_\perp\kappa_\parallel$ variation with the wave amplitude and respective to the actual value of the magnetic field diffusion coefficient. We note substantial differences in cross-field diffusion efficiency at the same perturbation amplitude, depending on the detailed form of the considered turbulent field. We confirm vanishing of $\kappa_\perp$ at 1-D and 2-D turbulent fields. For some types of turbulent magnetic field an initial regime of sub-diffusive transport appears in the simulations. The derived values of $\kappa_\parallel$ are weakly dependent on the wave form and scale as the inverse of the squared perturbation amplitude up to our highest non-linear amplitudes.

TRANSPORT IN BAROTROPIC TURBULENCE

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Here I review some recent results on the transport of passively advected tracers in barotropic turbulence and point vortex systems. In particular, I discuss the properties of absolute dispersion, the relationships between Eulerian and Lagrangian statistics, and the dynamics of a passive scalar field. Comparison with oceanic and atmospheric data is considered.

A COVARIANT THEORY OF THE INTRINSIC DRIFT OF OCEANIC MONOPOLES

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Being a fundamental oceanic transport mechanism, the intrinsic drift of monopolar vortices in the oceans has been subject of intensive observational and theoretical studies during the last decades.

We present a covariant theory of intrinsic drift of oceanic monopoles, based on shallow water dynamics. Being "covariant", the theory does not make assumptions about the precise geometrical structure of physical space. As a result, it is applicable to both the classical β- plane model and to a spherical model of the earth and it enlightens the correspondences between the two models.

On base of a slight extension of Noether's theorem. the theory relates the drift to broken symmetries of the underlying space and dynamics. In the case of the spinning terrestrial sphere, this refers to the spherical symmetry, which is broken by the earth's spinning: drift is related to the group and Lie algebra of rotations and therefore to angular momentum dynamics. In the case of the β-plane, well known formulae for drift of β- plane monopoles are recovered.

Application of the theory to the spinning sphere supports the widespread belief that steady oceanic monopoles travel along circles of constant geographical latitude. Formally, this result does not follow from the β- plane theories, because, according to formal foundations of the β- plane for shallow water (e.g. Verkley; J.A.S. 1990, vol. 47, p. 2453), the theoretical westward trajectories of monopoles on the β- plane correspond to great circles on the sphere.

HISTORICAL LAGRANGIAN DATA SET AT 2000 M IN THE WESTERN NORTH ATLANTIC

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The historical Lagrangian data set at 2000 m in the western North Atlantic is reanalyzed and compared to the 700 m level data set. Deep Lagrangian velocity spectra present a saturation at low frequencies as already observed higher up in the water column, but significantly less steep slope at high frequencies. The latter is linked to the numerous cusp-like features which are observed in most trajectories at this deeper level.
The results are interpreted both kinematically and dynamically, within the framework of geostrophic turbulence over large-scale topography.

GEOSTROPHIC RESPONSE OF THE YELLOW SEA TO TYPHOON PASSAGE

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The numerical model experiment is to study how typhoon parameters influence on the response of the Yellow Sea to the passage of typhoon . The typhoons are simulated by Gaussian function. As a result the followings become clear . Fast typhoons , with velocity of 8.5m/s , generate a chain of cyclonic / anticyclonic eddies , following the typhoon . Slow typhoons with velocity of 3 m/s generate only one cyclonic eddy , elongating along the typhoon track . To the right of the stretching cyclone , an anticyclonic eddy is formed . Both kinds of typhoons generate westward moving Rossby waves. The response duration is a function only of typhoon strength.

DENSITY AND CONCENTRATION OF ACTIVE AND PASSIVE TRACERS IN BURGERS FIELD

A.I.Saichev and **S.A.Lapinova** (N.Novgorod State University, N.Novgorod, Russia)

We have found the exact solution of equation $C_t + (\vec{v}\nabla)C = \nu\Delta C$ for tracers concentration at diffusion coefficient equals to viscosity one in a case, when generalized density field is satisfied to Burgers equation. It was analised behaviour and statistical characteristics of active tracers concentration in a 3-D case.

EFFECTIVE DIFFUSIVITY AS A MEASURE OF TRANSPORT.

Emily Shuckburgh (Centre for Atmospheric Science, DAMTP, Cambridge, England, CB3 9EW.)

Observations of chemical tracer show a sharp contrast across the tropopause. It appears that the tropopause may act, like the polar vortex edge, as a transport barrier that separates two well mixed regions. Isentropic advection studies are used to investigate this barrier and to quantify its leakiness. Particle studies and contour lenghtening calculations have often been used to quantify transport via rates of stretching and contour lengthening, however, they are unsatisfactory when transp ort barriers are leaky. A more appropriate diagnostic is one which is related to the position of the barrier such as the effective diffusivity developed by Nakamura. This quantity is expressed as a function of the latitude equivalent to an area, A, enclosed by a particular value of a quasi-conservative tracer on a given isentropic surface. This investigation has examined the relation of the effective diffusivity to stretching rates and hence its usefulness for identifying and quantifying transport barriers. In the case of a simple analytic velocity field where the transport structure is well understood it is shown that the effective diffusivity accurately marks regions of different mixing. When considering observed velocity fields from the stratosphere where there is a well defined polar vortex, diagnostics such as contour lenghtening rates may be used sucessfully. These results are compared with those from effective diffusivities. Observed velocities from isentropic surfaces intersecting the tropopause are then investigated, together with velocity fields from numerical simulations in which a clear tropopause is formed through the action of baroclinic instability.

VALIDATION OF A METHOD FOR DIAGNOSING THE PERMEABILITY OF A TRANSPORT BARRIER

A. H. Sobel and R. A. Plumb (Massachusetts Institute of Technology, Cambridge, MA, 02139, USA)

We attempt a synthesis of two distinct approaches to diagnosing the permeability of transport barriers such as the polar vortex edge. The first approach is the "modified Lagrangian mean" (MLM) theory, which relates the rate of change of the mass enclosed by a tracer isopleth to the sources and sinks of that tracer. The second involves a particle advection technique combined with an algorithm for removing fine-scale features. The primary disadvantages of MLM are practical, while advection-based techniques (including ours) are somewhat messy from a theoretical point of view, and typically require one or more free parameters.
We use MLM theory to diagnose the balance between potential vorticity forcing and dissipation in the polar vortex region of a shallow-water model of the stratosphere. All nonconservative terms are accurately known in the model (unlike in observational data) so MLM theory can be applied directly and is exact. The "advection plus truncation" technique is then applied as well, and shown to give comparable results. In particular, it is shown that the amount of mass removed by the truncation procedure is roughly the same (with parametric uncertainty of a factor of two) as that "transported", in the MLM framework, by the model's hyperdiffusivity, which is shown to act primarily on vortex filaments. The results suggest guidelines for using MLM with smoothed, rather than exact, tracer contours as the coordinate surfaces.

TRACER TRANSPORT BY STEADY AND UNSTABLE BETA-PLUMES WITH APPLICATION TO THE MEDITERRANEAN SALT TONGUE

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Simple analytic and numerical models are applied to the problem of the westward propagation of potential vorticity anomalies from an eastern boundary. Steady analytic solutions produce a balance between westward propagation by long Rossby waves and diapycnal mixing such that plumes of potential vorticity extend further to the west nearer to the equator. This results in a distribution of potential vorticity and large scale geostrophic shear that are in qualitative agreement with climatological observations of the Mediterranean salt tongue. The erosion of the potential vorticity signal to the west by mixing produces a change in sign of the zonal gradient of the potential vorticity field between the upper and lower portions of the Mediterranean salt tongue. Linear stability analysis and time dependent solutions obtained from a numerical model reveal that this structure is baroclinically unstable. At low latitudes the flux of potential vorticity is dominated by steady long Rossby wave dynamics, while at mid-latitudes the eddy fluxes resulting from baroclinic instability are dominant, consistent with simple scaling ideas. These results suggest that the shape of the Mediterranean salt tongue may be, at least in part, determined by its own internal dynamics and that baroclinic instability of the large scale Mediterranean salt tongue may contribute to the observed low frequency variability at mid-depths in the North Atlantic.

MIXING IN A STABLY-STRATIFIED SHEAR LAYER

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Kraig B. Winters (Applied Physics Laboratory, University of Washington, USA)

The analysis of mixing developed by Winters et al. (J.F.M., 289, 115-128) has been applied to high resolution direct numerical simulations of a shear layer performed by Staquet (J.F.M., 296, 73-126). Following Winters et al., mixing efficiency is defined by the ratio of a diffusive flux across the isopycnals to the dissipation rate of kinetic energy, instead of the volume averaged advective buoyancy flux to the dissipation rate of kinetic energy. Both definitions are compared in our work. They yield the same value of the mixing efficiency at large times only, when the flow dynamics are weakly nonlinear. This value compares very well with that found in the oceanic thermocline and the link with the flow dynamics is under study. When the flow dynamics are strongly nonlinear by contrast, only the definition based upon the diffusive flux is able to provide an instantaneous estimate of mixing efficiency, because it remains strictly positive.

ESTIMATORS FOR THE STANDARD DEVIATION OF HORIZONTAL WIND DIRECTION

R. O. Weber (Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland)

The dispersion of tracers in the atmosphere is mainly due to turbulent diffusion that is inherent in atmospheric motion. Realistic estimates of dispersion therefore require an accurate description of atmospheric turbulence. The standard deviation of horizontal wind direction is a central quantity in the characterization of atmospheric turbulence. It can be used to quantify lateral spread and is therefore of great practical use in dispersion models . Because the horizontal wind direction is a circular variable, its standard deviation cannot be directly estimated by on-line methods. For a mathematically strict determination of the angular standard deviation it is necessary to store all observations and perform off-line calculations. To characterize atmospheric turbulence, fast measurements on a time scale of 1 second are necessary. This leads to a huge number of data that must be stored and analyzed off-line for a strict calculation of the angular standard deviation. A more practical approach is to calculate on-line moments of linear variables and to parameterize angular standard deviation in terms of these moments. We compare a variety of such estimators by means of a large dataset from an ultrasonic anemometer. It is systematically investigated which types of linear variables lead to best estimators and which parameterizations are best within each group of linear variables. Estimators based on moments of the sine and cosine of the wind direction turned out to be most robust. The parameterizations based on an isotropic Gaussian model of turbulence give estimators with smallest error within the different groups.

OA35/NP4.1 Nonlinear waves, instabilities and wave flow interactions

Convener: Shrira, V.I.
Co-Conveners: Ostrovsky, L.A.; Velarde, M.G.

A SIMPLE MODEL STUDY OF TROPOSPHERIC MERIDIONAL CIRCULATION BASED ON SAGE II OBSERVATIONS

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This study investigates the tropospheric mean meridional circulation important to the development of opaque clouds and the performance of the 1.02-μm channel of the Stratospheric Aerosol and Gas Experiment (SAGE) II in the troposphere. A simple empirical model is formulated to derive the mean meridional circulation from the 6-year (1985–1990) statistics of the SAGE II tropospheric measurement frequency. The derived mean meridional circulation reveals a distinct pattern of material advection into the upper troposphere from both the lower troposphere and the stratosphere. Most significantly, the empirical model circulation is shown to be highly consistent with the observed distributions of the free tropospheric aerosol and ozone concentrations, particularly with their seasonal variations given the respective source regions. This high degree of consistency illustrates the intimate relationship between the large-scale circulation, cloudiness, and the SAGE II tropospheric measurement frequency, and the robust nature of the empirical model despite the model's simplicity.

LAGRANGIAN TRANSPORT IN FLOWS WITH APERIODIC TIME-DEPENDENCE

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Over the past 10 years the analogy between the global, geometrical study of nonlinear dynamical systems and Lagrangian transport and mixing studies in fluid mechanics has been used to obtain a deeper understanding of Lagrangian transport issues in a variety of flows. However, the vast majority of this work has been in the context of two-dimensional, time-periodic flows. This is due to the fact that through time periodicity the study of the equations for fluid particle trajectories can be reduced to the study of a two-dimensional area-preserving Poincaré map, and once the problem has been cast in this setting a variety of well-known techniques and ideas from dynamical systems theory can be applied for the purpose of studying fluid transport and mixing issues. For example, KAM tori represent barriers to fluid transport and mixing, chaotic dynamics should act to enhance mixing, and invariant manifolds, such as the stable and unstable manifolds of hyperbolic periodic points, are manifested as "organized structures" in the fluid flow.
In this talk I will discuss how much of this framework and point-of-view carries over to flows having a general time-dependence. In particular, the notions of invariant manifolds, lobes, and chaos will be discussed. Many of the ideas will be described in the context of specific geophysical flows, in particular meandering jet models of the Gulf stream and Rossby wave flows.

ASYMPTOTIC ANALYSIS OF A STOKES WAVE MODULATIONS

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Evolution of a three-wave system composed of a Stokes wave and two initially small sidebands is considered analytically and numerically within the framework of the Zakharov integrodifferential equation. A pair of symmetric sidebands is chosen to provide either four-wave (type I) or five-wave (type II) instability of the carrier. For type I instability, the asymptotic solution to the leading order is expressed through elementary functions. Simple expressions for the amplitude and period of the modulations are found. Maximum amplitude modulations are shown to have infinite period; this case corresponds to complete and irreversible transfer of energy from the carrier to sidebands. Three-dimensional instability of this type is shown to exist within a certain limiting angle of the sidebands orientation.
For five-wave interactions, the solution within the domain of instability is found to be elliptic, to the leading order. Conditions of maximum amplitude of the modulations and of infinite period are formulated. A simple solution in terms of elementary functions is obtained along a certain curve in the parameter space. Results are compared with linear instability analysis and numerical simulations.
The work was supported by US Office of Naval Research (Grant N00014-94-1-0532) and by INTAS (Grant 93-1373).

THEORETICAL AND EXPERIMENTAL INVESTIGATION OF NONLINEAR SURFACE WAVES EVOLUTION IN FIELD OF INHOMOGENEOUS CURRENTS

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The transformation of counterstream nonlinear quasimonochromatic surface waves on local perturbation of current is investigated. The model equation, describing the variation of surface waves amplitude has been derived. The temporal evolution of initially homogeneous wave field is numerically investigated in the framework of this equation for cases one-dimensional and two-dimensional perturbations of current. It is shown, that even weak inhomogeneous currents modifies appreciably the regime of Benjamin - Feir instability develop. With increasing time the value of nonlinear surface wave amplitude change at first increase, and then leaves on a stationary level, but the surface anomaly structure still continues to grow in complexity. The theoretical model has been checked experimentally in laboratory tank. The inhomogeneous stream was created by flow around submerged sphere, surface waves were generated by wavemaker. Two-dimensional patterns of surface wave amplitude were registered. Comparison of experimental data with results of theoretical calculations has shown, that the offered model well describes main features of transformation of nonlinear surface waves on non-uniform perturbations of current.

THE EFFECT OF CONTINUOUS SHEAR UPON THE TWO-LAYER MODEL OF BAROCLINIC INSTABILITY

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The two-layer model of baroclinic instability is modified to include small continuous variations of the velocity and density profiles. It is demonstrated that, if the difference between the average upper-layer velocity and the velocity of the lower layer is negative (westward), the flow is unstable. Interestingly, the unstable disturbances are smooth and do not have the logarithmic singularity, which are commonly believed to destabilise the flow. The instability is interpreted as a resonance between Rossby waves and a certain "shear mode" supported by the vertical shear of the mean flow.

ANALYTICAL SOLUTIONS OF THE NONLINEAR SHALLOW WATER EQUATIONS AND THEIR AVERAGING ON A PLANE BEACH.

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The part of a beach over which the instantaneous shoreline moves back and forth as waves meet the shore is known as the swash zone. Flow properties in the swash zone have significant effects on coastal erosion and accretion, as well as influencing ground water flow and flood protection. This theoretical study uses the nonlinear shallow water equations (NLSWE) as a model for the swash zone and the nearby region on a plane beach of gentle slope. We first examine some properties of the inviscid analytical solution of the NLSWE given by Carrier & Greenspan (1958). We show that two equivalent dimensionless representations of the flow are possible and their relationship to dimensional properties is illustrated. We also show that analytic solutions are possible for a weakly three-dimensional extension of their solution which uses the approximation of Ryrie (1983). Far from the shoreline ($\sigma = 0$), where nonlinear effects are small and the water is deep, the patterns of longshore velocity and free surface elevation are very similar (absolute difference is less than 0.3% for $\sigma > 4$). Results for the main flow properties of both single- and multi-mode solutions are given in the form of contour plots. A speculative discussion is given on the difficulty in defining a suitable mean shoreline. Mean flow properties of the flow inside the swash zone are computed for these solutions.

STRUCTURE OF BAROCLINIC WAVES AND ZONAL JETS IN AN INTERNALLY HEATED, ROTATING CYLINDER OF FLUID.

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Here we report new laboratory experiments performed in a rotating 'almost-open' cylinder of fluid, subject to internal heating and cooling at the outer side wall, in which the formation of stable eddy structures and their role in forcing multiple zonal jets was investigated. A background radial vorticity gradient was simulated by the inclusion of oppositely sloping end walls. The boundaries were arranged so that the fluid depth (D) increased with radius ($\partial D/\partial r > 0$) and decreased with radius ($\partial D/\partial r < 0$). Experiments have also be performed with horizontal boundaries (f-plane) to identify how the simulated β-effect modifies the flow regimes of these internally heated flows.
Stable, coherent, regular eddy features are observed in both f-plane and β-plane experiments. The regular eddies seen in the $\partial D/\partial r > 0$ ($\partial D/\partial r < 0$) end wall experiments are found to be 'vertically trapped' close to the bottom (top) boundary. This vertical trapping may be a consequence of the structure of the azimuthally-averaged zonal mean flow generated by the two opposite end wall configurations and its respective strength at each different level in the fluid. Within the non-axisymmetric flow regimes of all three end wall configurations the number of zonal jets observed in the lateral domain of the experiment is larger than expected from the form of the thermal forcing. Their radial scale is, however, much larger than the Rhines scale, suggesting that L_β cannot be used to predict the radial wavenumber of the mean flow in these strongly forced baroclinic experiments.

DISTORTION OF LONGITUDINAL STRAIN SOLITONS IN NONLINEAR ELASTIC WAVEGUIDES

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Propagation of longitudinal solitary waves in the inhomogeneous rod and plate is studied both theoretically and in experiments.
The main features of soliton's focusing or decay in a rod with varying cross section area (geometric inhomogeneity) is found to consist in simultaneous variation of both the amplitude and the width of solitary pulse and its front's distortion. The problem of soliton propagation in a rod with varying nonlinear elastic moduli (physical inhomogeneity) is solved also.
Transverse distortion (diffraction) of a strain solitary wave with initially plane front inside a homogeneous 2D- waveguide (a plate) is studied.
The obtained results are compared with our pioneering experimental data on generation and focusing of longitudinal strain solitons.
It is shown the possibility of an energy transport by means of elastic compression solitons through highly (linearly) dissipative wave guide.

PROPAGATION INTERNAL GRAVITY WAVES IN UNSTEADY INHOMOGENEOUS STRATIFIED MEDIUM

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A ocean water stratified structure leads to emerging of internal gravity waves (IW). In reality, the water density depends not only on the vertical variable, but also on the horizontal variables and time. The problem of IW generation by a point source moving in a stratified medium varying with respect to all spatial variables and time is considered. The fact that the characteristic horizontal and temporal scales of density variation may be large as compared with lengths and periods of IW makes it possible to solve this problem by means of an approximate method analogous to the WKB method. In our early paperss was shown that the far IW field is a sum of individual modes each of which is enclosed within its own Mach cone, the asymptotic form of each mode near the corresponding wave front being expressed in terms of certain special functions. Therefore, in investigating the problem of IW generation by a point source moving in a stratified horizontally inhomogeneous unsteady medium solution for individual mode must be sougth in the form of waves of a special type - Airy and Fresnel waves, where special functions allow to describe IW field structure both near and far from individual mode wave front. Then the problem is reduced to the solution of the eikonal equation with some conservation laws perfomed at its characteristics. Numerical calculations for a real ocean parameters show that an appreciable deformation of IW wave front each mode and the variation ot the wave amplitude occur when horizontal inhomogeneity and density unstability are present in ocean. This research was supported by Russian Foundation of Basic Researchers, Grant 96-01-01120.

THREE-DIMENSIONAL NONLINEAR EVOLUTION OF WATER WAVES: A LABORATORY STUDY

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To study the formation and the development of three-dimensional gravity wave patterns due to five-wave resonant interactions, an experiment has been designed in the large IRPHE-Luminy wind-wave facility. The water surface of the tank was covered by a thin floating plastic film and two-dimensional water waves were generated by the submerged paddle and then amplified by the wind. The evolution of the wavetrains with frequency and steepness was studied by using capacitance wave gauges. These observations first show that three-dimensional 'horse-shoe' patterns emerge from the plane waves at a certain fetch when the wave steepness reaches a critical value. These perturbations grow only for particular wave frequencies. Their transverse scales are determined by the resonant boundary condition at the sidewalls but the associated values of the nondimensional transverse wavenumber range in a very narrow domain. Finally, two types of horse-shoes patterns have been identified :

- the 'classical' one with a double period of modulation resulting from the interaction between the basic wave and two symmetric oblique perturbations (Mc Lean, 1982; Shrira, 1996) ;
- a 'new' one with a triple period of modulation resulting from the interaction between the basic wave and two non-symmetric oblique perturbations.

The work was supported by US Office of Naval Research (grant N00014-94-10532)

ON THREE-DIMENSIONAL LONG INTERFACIAL WAVE PROPAGATION NEAR THE CRITICAL DEPTH LEVEL

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The propagation of interfacial waves near the critical depth level in a two-layered fluid system is investigated. We first derive an evolution equation for weakly nonlinear and dispersive interfacial waves propagating predominantly in the longitudinal direction of a slowly rotating channel with gradually varying topography and sidewalls. The new evolution equation includes both quadratic and cubic nonlinearities. For interfacial waves propagating in certain type of non-rotating channels with varying topography, we find two families of periodic solutions, expressed in terms of the snoidal function, to the variable-coefficient equation. As the limiting cases of these periodic-wave solutions, a family of solitary-wave solutions and an isolated shock-like wave solution are also obtained. By recasting the evolution equation into Hirota's bilinear form, we also find the two-soliton solutions. In a rotating uniform channel, our small-time asymptotic analysis and numerical study show that depending on the relative importance of the cubic nonlinearity to quadratic nonlinearity, the wavefront of a Kelvin solitary wave will curve either forwards or backwards, trailed by a small train of Poincaré waves. When these two nonlinearities almost balance each other, the wavefront becomes almost straight-crested across the channel, and the trailing Poincaré waves diminish.

HYDRODYNAMIC MODEL OF THE DEVELOPMENT OF THE TOPOGRAPHY ELEVATIONS AT THE MID-OCEAN RIDGES.

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Ridge crest depth variations recently have been recognized as an important features of spreading process. The goal of our investigation is an accounting the development of topography elevations at the ocean floor related to dynamical effect of mantle advection beneath the mid-ocean ridges. Hydrodynamical model is to be elaborated to calculate time-dependent behavior of ocean floor deformations. The mantle is to be treated as a half- space in which flow is represented as upwelling driven by spreading. Deformations of the boundary associated with development of time-dependent flow disturbances are calculated. It is considered the stability of the stationary flow of high viscosity liquid in the frame of two-dimensional linear theory. It is suggested this solution to be considered as a flow caused by the force acting along the boundary deformable surface. The requirement the solution does not increase at infinity of space let to determine the frequencies of the oscillations. This work was done under support of ISF grant M09300.

NONLINEAR STABILITY OF A SLIGHTLY STRATIFIED FREE SHEAR FLOW

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We examine the spatial evolution of an instability wave excited by an external source in a free, nearly nondissipative, stably stratified shear flow with a small Richardson number $Ri \ll 1$. It turns out that at the nonlinear stage of evolution even so small a stratification modifies greatly the evolution behaviour compared with the case of a homogeneous flow. We have investigated (analytically and numerically) different stages of evolution corresponding to different critical layer regimes, as well as determined the formation conditions and structure of a quasi-steady nonlinear critical layer. It is shown that the stratification influence upon the nonlinear evolution radically depends on the sign of $(Pr - 1)$. Thus, when Prandtl number $Pr < 1$ the amplitude in the course of the evolution varies in a limited range and either reaches the saturation, when the linear growth rate γ_L is small enough or, at higher γ_L, performs quasi-periodic oscillations, whose structure becomes increasingly complicated with increasing γ_L. When $Pr > 1$ sratification leads to the appearance of new evolutionary stages, namely the stage of explosive growth in the unsteady critical layer regime, and the stage of essentially unsteady evolution in the nonlinear critical layer regime, and to a modification of the power-law growth in the regime of quasi-steady nonlinear critical layer.

QUASI-STEADY REGIMES OF NONLINEAR DEVELOPMENT OF DISTURBANCES IN SHEAR FLOWS AND NONLINEAR CRITICAL LAYER AS THE RESULT OF EVOLUTION

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A study is made of the formation of a nonlinear critical layer (the hypothesis on it's existence was first proposed by Benney & Bergeron 1969 and Davis 1969) in homogeneous and weakly-stratified incompressible shear flows in the course of the development of initially small unstable disturbances, whose growth rate is so small that all the evolution proceeds in the so-called "quasi-steady" regime. It is shown that such an evolution can be described from start to finish analytically using a pair of evolution equations for the wave amplitude and phase which involve universal functions of the familiar Haberman (1972) parameter, λ, that characterizes the relative importance of the dissipation and nonlinearity. In addition to the well known function of a "logarithmic phase jump" that was introduced and investigated by Haberman (1972), evolution equations generally contain also other functions of λ. In this work we introduce and study (numerically and analytically) another three such functions.

COLLISION BETWEEN A SOLITON AND AN ENVELOPE SOLITON

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The gravity wave theories of short waves (Stokes theory) and long waves (shallow water theory) are never valid simulteanously. Thus study of the interaction between long and short waves need to develop a more general approach. A perturbation method of nonlinear WKB type gives a gravity wave theory able to describe short and long waves simulteanously. Then it is possible to investigate the interaction between all stationary solutions of the Korteweg and de Vries equation and all stationary solutions of the cubic Schrödinger equation. We consider more particularly the interaction between a soliton and an envelope soliton. The main results are phases shifts, waves numbers and frequencies variations (Doppler effect) and vertical variations of the phases.

SOLITARY INTERNAL WAVES WITH RECIRCULATION CELL.

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Solitary wave disturbances are often observed to have recirculating cells. Currently, the only avaiable solution to this problem in the context of internal waves are Long's vortices in shallow fluid. However, it was shown numerically that profile of stratification inside the vortex that was used by Long leads to the instability of the solitary wave. In the present report a new tractable model for wave with recirculation cell will be presented. Fluid inside the vortex is assumed to be homogeneous due to the mixing. It is shown that amplitude of such disturbunce obey nonlinear dispersive equation, which includes nonlinear forcing due to the vortex. In the contast with small amplitude models the obtained equation predicts broadening of wave above a certain amplitude. Dependence of Froude number vs amplitude is also shown to be different from that predicted by the existing wealky nonlinear models. Our results are consistant with available numerical studies and natural observations.

LARGE AMPLITUDE CAPILLARY- GRAVITY SOLITARY WAVES AND INTERNAL WAVES

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We study the propagation of plane gravitational solitary waves on the interface separating two deep fluid layers with different surface tensions. The lower fluid is assumed to be stratified just below the interface. It is shown that solitary waves of finite amplitude are governed by an integro-differential equation valid up to the breaking level. This equation contains both the KdV and BO dispersion laws and a specific nonlinearity. Capillary KdV type or gravitational BO type of dispersion dominates if the thickness of the stratified layer is d << d* or d >> d*, respectively. The value d* depends on parameters characterizing stratification, shear and capillarity effects. We also show how changes in background stratification and shear alter the phase speed, shape and stability of the waves. The unusual effect of stabilization of the wave when shear increases is explained. We also describe experimental conditions under which capillary-gravity waves of solitary type can be observed.

NON LINEAR EFFECTS OF SPATIAL DISTRIBUTION OF ELECTROMAGNETIC WAVE'S ATTENUATION DUE TO AEROSOLS IN THE EARTH'S ATMOSPHERE

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This report presents new results in investigation of recently found non-linear effects in spatial distribution of attenuation of electromagnetic waves in the Earth's atmosphere due to aerosol component, in particular, it concerns of attenuation of solar radiation. These effects was found from the calculations according to earlier developed aerosol radiation model of the atmosphere. The model is initialised by the data on variation of the main meteorological parameters of the atmosphere, such as temperature, pressure, density, zonal and meridional winds, spectra of which was received as a result of non-linear interactions in the Earth's atmosphere.
The carried calculations show, that non-linear effects in spatial and temporal distribution of radiation attenuation are taking place in the atmosphere and that the spatial variations of the distribution laws are different for various periods.

NONLINEAR PARASITIC CAPILLARY WAVES

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We develop a new method for calculating steady parasitic capillary waves generated by wind-forced gravity waves. Using a viscous boundary layer approximation near the surface, the model enables us to efficiently compute nonlinear parasitic capillaries. In order to maintain a steady wave profile, wind forcing is needed to balance viscous dissipation and is represented by a sinusoidal pressure distribution at the surface. We show that the strength of parasitic capillaries depends on two parameters: the amplitude of the longer gravity wave and the amplitude of the forcing. Steady waves are possible only for amplitudes of the forcing higher than a certain threshold. Further, we demonstrate how parasitic capillaries affect the dissipation and dispersive properties of the waves. In particular, a significant deviation from the dispersion curve for linear gravity-capillary waves is found. Parasitic capillary waves strongly enhance the damping of longer gravity waves (by as much as one order of magnitude). A sharp cut-off in the spectra of gravity-capillary waves at higher wavenumbers is also discussed. The theoretical results show good agreement with experimental measurements.

THE DISTRIBUTION OF WAVE CREST HEIGHTS: OBSERVATIONS AND SECOND ORDER SIMULATIONS

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Qualitatively, the sharpening of the crests of surface waves is the most obvious manifestation of nonlinearity in the ocean. Yet a detailed quantitative description of this phenomena accurate enough for engineering use remains elusive. Many empirical and heuristic descriptions have been proposed, but their predictions differ considerably. Part of the lack of agreement is due to the difficulty of making measurements that accurately record the true height of the wave crests. Surface following buoys effectively cancel out the second order nonlinearity by making a Lagrangian measurement. Pressure transducers filter the nonlinear components of the signal in complicated ways. Wave staffs have varying degrees of sensitivity to spray. The location of the instruments also plays an important role. We have clear evidence from measurements in the North Sea that spurious crests due to spray are much more of a problem downwind even from mounting supports that appear transparent. Much of the theoretical nonlinearity can be captured by calculations correct to second order. Explicit calculation of the interactions of each pair of components in a directional spectrum is straightforward although computationally intensive. This technique has the advantage that the effects of wave steepness, water depth, and directional spreading are included with no approximation other than the truncation of the expansion at second order. Comparisons with measurements that we believe to be of the best quality show good agreement with these second order calculations.

INVERSE CASCADE AND ROSSBY WAVES IN THE KOLMOGOROV FLOW ON THE β PLANE.

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We study the large-scale instability of the two-dimensional Kolmogorov flow $u = (-\sin y, 0)$ modified by the β effect. The resulting β-Cahn-Hilliard equation for the large-scale flow, $\partial_T \partial_X \psi(X,T) = \partial_X \left(\left(\lambda_1 (\partial_X \psi)^2 - \lambda_2 \right) \partial_X^2 \psi \right) - \lambda_3 \partial_X^5 \psi - \beta\psi$, is characterized by a linear instability of the negative viscosity type and by the presence of both nonlinear and dispersive terms.
The large β limit leads to a new equation for resonant Rossby waves which is integrable (Frisch, Legras and Villone, 1996, Physica D, 94, 36-56).
For small values of β, numerical integrations of the β-Cahn–Hilliard equation shows that the arithmetic cascade towards the largest scale of the flow, which characterizes the solutions of the standard Cahn-Hilliard equation, is stopped at intermediate wavenumbers. This behaviour has been often advocated phenomenologically within the context of geophysical flows (Rhines, 1975, J. Fluid Mech., 69, 417-441). Here, it is proved analytically by a singular perturbation method and shown to result from the competition between dispersive effects growing with scale and interactions between solitons decaying exponentially with distance. This prediction is compared to the results of numerical simulations. We hope to present also results on the basins of attraction of the solutions stabilized by β.

MODELLING OF THE NONLINEAR WAVE PROCESSES USING THE GRAVITATIONAL CAPILLARY WAVES IN THIN LIQUID LAYERS

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The MHD-phenomena in the aqueous electrolytes may be used to generate both standing and running gravitational capillary waves (GCW). The proposed technique is based on excitation of the pulse horisontal mass-force in the inlet or middle part of the open channel. Due to transmission of the short-term pulses the initial current velocity of ab. 10 cm/s is provided at 0.5 Tl-induction, which may be compared to the GCW-speed. It has been revealed that the initial conditions may be set with the desired accuracy by variation of an amplitude and a form of a pulse. Variation of the medium dispersion, that is a nonlinearity relation, is provided by varying of the liquid layer depth. Generation of striking waves having combs and dips with 0.5-mm amplitude and 4-8 cm length has been also observed. Additionally, the behavior of internal wave has been studied, particularly, in the boundary layer kerosene-electrolyte. Thus, the suggested technique allows to study and model different non-linear processes in the dispersive media, described by the Korteweg - de Vries - Burger equation, to model and study the tsunami-phenomena, the waves in the shelf regions, the wave processes in the ocean related to the periodic and nonperiodic variation of the tangential component of the integrated gravitational fields, defined by interaction of the Earth and other planets.

NUMERICAL SIMULATION OF WAVE BREAKING IN WATERS OF FINITE DEPTH BY USING A VOF METHOD

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The investigation of wave induced coastal dynamics is of practical importance in oceanography and in coastal engineering. In the mediterranean, the main forcing at the origin of beach erosion is the wave breaking.
In the present paper, a numerical simulation of the wave breaking is presented. The discretization of the equations is obtained through finite volumes with a 3D cartesian staggered mesh. The free surface description is based on the concept of a fractional volume of fluid (VOF).
Studies concerning the wave shoaling and breaking are reported for different sloping beach shapes. Comparisons with experiments concerning the surface deformation and the velocity fields are presented.

EFFECTS OF ROTATION ON FLUID MOTIONS IN CONTAINERS OF VARIOUS SHAPES AND TOPOLOGICAL CHARACTERISTICS

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Combined experimental and theoretical work on mechanically-driven flows in homogeneous fluids in cylindrical containers of various shapes and topological characteristics in general rotation relative to an inertial frame of reference have elucidated the conditions under which relative motion is unaffected by gyroscopic (Coriolis) forces (*J. Fluid Mech.* **32**, 737, 1968). The theoretical work is extended here to cases when the action of gravity (and centripetal forces) on density inhomogeneities have to be taken into account. A novel theoretical basis is thus provided for certain experimental studies of flows due entirely to buoyancy forces, in which a variety of hydrodynamical processes of interest in dynamical oceanography and meteorology (e.g. sloping convection, fronts, jet streams, western boundary currents) are investigated under controlled laboratory conditions. The experimental discovery of systems for which total advective heat transport is virtually independent of the rate of rotation of the apparatus raises questions upon which considerations of the behaviour of the helicity, superhelicity and potential vorticity pseudo-scalars appear to bear. (See *Geophys. Astrophys. Fluid Dyn.* **48**, 69, 1989; *Dyn. Atmos. Oceans* (in the press), 1997.)

THE INTERACTION OF SOLITARY WAVES IN AN UNSTABLE ENVIRONMENT

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A quasi-geostrophic two-layer model is used to investigate the generation and interaction of solitary waves propagating on a baroclinic current, which has the possibility to be baroclinically unstable. This situation leads to wave growth followed by saturation, described asymptotically by two coupled Korteweg-de Vries equations. This asymptotic system contains a very rich solution set, consisting of complicated patterns of solitary wave interactions. We will describe numerical solutions of the coupled Korteweg-de Vries equations, supplemented by perturbation analyses, as well as numerical simulations of the full quasi-geostrophic two-layer equations. Applications to oceanic and atmospheric phenomena will be discussed.

VACILLATION CYCLES AND BLOCKING IN A CHANNEL.

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A 2-layer, β-plane, quasi-geostrophic channel model is used to examine the interactions between an upper-layer jet and high-frequency eddies supplied from a wavemaker in the lower layer. For certain initial jets, a dipole similar to an atmospheric block is formed, which remains stable to large-amplitude. By adding a shear to the upper-layer jet, a low-freqeuncy vacillation cycle is induced, whereby the high-frequencies excite a split in the jet, which breaks down due to instability. This instability is demonstrated using a local instability analysis technique, and is also reflected in energy diagnostics. The role of the high-frequency eddies through the various phases of the cycle is also examined.

These results suggest that the meridional shear in the upper-level atmospheric jetstream may determine whether blocking would develop, persist or breakdown. The structure of the upper-level jet could be controlled by seasonal variations or large-scale teleconnection patterns.

MASS TRANSPORT OF NON-LINEAR INTERNAL WAVES ON THE CONTINENTAL SHELF

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Previous comparisons between KdV type wave theory and oceanographic observations have considered the displacement of isopycnal surfaces. Here we consider the velocity field of non-linear internal waves. We present detailed observations of tidally generated non-linear internal waves on the continental shelf west of Scotland. Comparison is made between the observed mass transport and analytic expressions for the mass transport in a two layer system which are consistent with the traditional KdV theory. Implications to the oceanographic use of KdV type theories are discussed.

PERIODIC AND SOLITARY SOLUTIONS OF THE EVOLUTION EQUATION FOR NONLINEAR INTERFACIAL WAVES BETWEEN TWO LIQUID LAYERS

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This paper deals with the development of the differential model [1]. The initial hydrodynamic equations were reduced to the evolution equation for three-dimensional perturbations of the interface. The new model was obtained for weakly nonlinear waves of arbitrary lengths in a two-layered system with gently sloping solid boundaries and has the second order of an accuracy. The value of characteristic velocity of propagation may change in a wide range. Periodic and solitary solutions of the evolution equation were found numerically. The method [2] was used for plane disturbances running between horizontal bottom and cover. Solitary solutions are in a good agreement with the experimental data [3,4].

This work has the financial support of the Russian Basic Research Foundation (grant N 96-01-01766).

SOLITARY LAMB"S WAVES IN THE ATMOSPHERE

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In last years the many researchers try to modeling various solitary wave in neutral atmosphere and ionosphere. Basic equations system describes the atmosphere in spherical coordinates. For simplicity the one-dimensional traveling wave decision is considered:

$v = v(\tau),\ u = u(\tau),\ \rho = \rho(\tau), \quad where\ \tau = \varphi - \alpha t$

$\left(\frac{u}{a \sin v} - \alpha\right) \cdot \frac{\partial u}{\partial \tau} = -2\overline{\omega} v \cos v - \frac{c^2}{a \sin v \rho_0} \frac{\partial \rho}{\partial \tau}$

$\left(\frac{u}{a \sin v} - \alpha\right) \cdot \frac{\partial v}{\partial \tau} = 2\overline{\omega} u \cos v$

$\left(\frac{u}{a \sin v} - \alpha\right) \cdot \frac{\rho}{a \sin v} \frac{\partial u}{\partial \tau}$

To solve the system after excluding ρ we get v' and u' as functions of u and v. Expanding these functions in Taylor series near the equilibrium point (0,0) and taking linear and square terms, that it is necessary at increase wave amplitude we can obtain sollution in kind $u(\tau) = U_0 \sec h^2(\mu(\tau - \tau_0))$.

Linear wave speed $\alpha\beta \subset [220, 272]$ when his amplitude does not exceed 50 m/s. The solitary wave width on half level decreases at increase of solitary wave amplitude. In middle latitude the solitary wave was about 7 thousand kilometers at amplitudes 10 - 50m/s. We experimentally defines the most probable characteristics of Lambs solitary wave on meteor hights. The amplitude of zonal wind velocity in solitary wave $U_0 = 20 \pm 12$ m/s, horizontal sizes D=2-6 thousand km, vertical 3-6 kms., temporary sizes was 3 - 7 hours.

THE HAMILTONIAN DESCRIPTION OF WAVES IN A NON-UNIFORMLY ROTATING FLUID

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A Hamiltonian theory of nonlinear interaction of Kelvin and Poincaré waves in a layer of rotating fluid, of barotropic Rossby waves in the β-plane approximation, and of barotropic and baroclinic Rossby waves on a sphere and inside a rotating paraboloid is constructed. The latter case is of particular interest because setups of such a geometry are used for laboratory modelling of Rossby waves on the globe. The transformations of ordinary physical variables to normal canonical variables are found for baroclinic and barotropic Rossby waves in a spherical layer of fluid in the rigid lid approximation and in the presence of free surface. These normal variables are used for calculation of the coefficients of three-wave interaction of Rossby waves and for analysis of stability of quasimonochromatic trains of these waves with respect to self-modulation and self-focusing. On the basis of the theory developed the self-action of barotropic Rossby waves on a β-plain, the decay instability of short Kelvin waves in the presence of a given long Poincaré wave, as well as stabilization of the decay instability due to phase mismatch of the interacting waves on cubic nonlinearity of the medium are studied. The growth rates of the decay and modulational instabilities are estimated for typical parameters of the oceanic waves.

THE EFFECT OF NEGATIVE TURBULENT HEAT CONDUCTIVITY AND ITS ROLE IN THE TROPICAL CYCLONE FORMATION

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The effect of negative turbulent heat conductivity is observed under conditions of thermally insulated boundaries and high intensity of the turbulent convection, giving rise to small-scale moving heat carriers in a fluid, so-called thermals. This phenomenon is based on the long wave instability, that is caused by the evolution of random heat perturbations creating a horizontal temperature gradient. Such instability is accompanied by the appearance of convective heat flux, generated by the small-scale moving thermals, in the direction of average temperature horizontal gradient. This leads to the growth of initial heat perturbation and its horizontal scale. Thus, we obtain an anisotropy (and even to change in a sign) of the turbulent heat conductivity coefficient, and we can interpret this coefficient as a some tensor. The components of this tensor are determined by respective heat fluxes. The quantitative estimates for the heat fluxes along horisontal and vertical directions have been obtained by substitution of our experimental data and meteodata for tropical atmosphere into our theoretical model, which has been presented at XXI General Assembly of the EGS. The revealed mechanism acts on the initial stage of tropical cyclone evolution (on the stage of initial tropical perturbation) and provides the transformation from the small-scale cumulus cloudiness to the atmosphere state with cloudy clusters. This work is supported by RFFI under Grant N 95-01-01094a.

OBSERVATION OF AN INTERNAL WAVE ATTRACTOR

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When a bucket of water is shaken, it responds by vibrating in terms of large-scale standing waves: its eigenmodes. The belief that enclosed continuous media *always* possess eigenmodes is deeply rooted. It will be shown here that internal gravity waves in stably-stratified fluids in non-trivially shaped containers present a counter-example. In this case, regardless of the forcing location and shape, waves propagate towards an attractor determined by the forcing period. At the attractor these waves intensify, leading to mixing, which is of vital importance for marine processes. Inertial (gyroscopic) waves due to the Coriolis force behave in a similar way, and this should be relevant for oscillations of the earth liquid core. The appearance of attractors rather than eigenmodes leads to the unexpected mathematical result, that a linear equation can be solved by iteration of a nonlinear map, and possesses solutions with a fractal spatial structure which depends fractally on the parameters involved. Video demonstrations of several laboratory experiments and related theoretical models capturing the internal wave attractor will be presented.

INSTABILITIES OF CONTINUOUSLY STRATIFIED ZONAL EQUATORIAL JETS IN A PERIODIC CHANNEL MODEL

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Several numerical experiments are performed in a multilevel periodic channel model centered on the equator with different zonally uniform background flows which resemble the South Equatorial Current (SEC) and the Equatorial Undercurrent (EUC). Analysis of the simulations focuses on identifying stability criteria for a continuously stratified fluid near the equator. Particular emphasis is given to the effects of stratification on the stability of the mean flow. We show that the equatorial region is baroclinically unstable during specific thermal conditions that are ultimately induced by the wind. A 90m deep mixed layer is required to destabilize a zonally uniform, 10 degree wide, westward surface jet that is symmetric about the equator and has a maximum velocity U_0= 100 cm/s. In the ageostrophic regime we find that there is a critical upper bound on the stratification of the mean flow corresponding to a vertical temperature gradient of O(1) °C for a 90m deep mixed- layer. When the westward surface parabolic jet is made asymmetric about the equator in order to simulate more realistically the structure of the SEC in the eastern Pacific, two kinds of instability are generated. The oscillations that grow north of the equator have a baroclinic nature while those generated on and very close to the equator have a barotropic nature.

THE NORMAL FORMS FOR THE SHALLOW WATER EQUATIONS

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The extention of Poincare normal form for systems of partial differential equations, which have linear ordinary equations, as a main part, is obtained. Poincare normal forms for the shallow water equation on beta-plane and in large scale (with respect to Rossby radius) for the variable Coriolis parameter are found. The normal form of the shallow water equations contains the Charney equation and higher approximation equations for Rossby waves. Normalized transformation allows to write formulas for the slow invariant manifold.

Antisymmetric normal form for noncanonical Hamiltonian systems is constructed, which guarantees an exact conservation of energy. The forms for the shallow water equations and the equations of ion-acoustic waves in magnetic fields are found.

PERIODIC INVERSE SCATTERING TRANSFORM: NONLINEAR FOURIER ANALYSIS WITH CNOIDAL WAVE AND HIGHER ORDER BASIS FUNCTIONS

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I give a general scenario for the study of nonlinear shallow water wave motion which caries the inverse scattering method to one order of approximation higher than that of the Korteweg-deVries equation. The higher order equation is found using Whitham's approach and a variation on this equation is found to be integrable by the inverse scattering transfonn. I show how to construct the hyperelliptic flow of the equation and linearize the flow to obtain the theta function formulation. Thus nonlinear Fourier analysis in terms of theta functions is fully established. The single degree of freedom solution (i.e. the basis function for the nonlinear Fourier decomposition) is approximately a cnoidal wave for small amplitudes; for larger amplitudes the basis function is higher and narrower than the cnoidal wave and reaches a maximum degree of nonlinearity at a peaked form which approximates the 'highest wave'. Using these basis functions I analysis both laboratory and Adriatic Sea surface wave data. It is conjectured that even higher order equations may also be integrable for the shallow water case.

EXPERIMENTAL MEASUREMENTS OF SHALLOW WATER WAVES: ANALYSIS WITH THE EXTENDED ORDER INVERSE SCATTERING TRANSFORM

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We discuss the measurements of shallow water surface waves in one space and one time dimensions. The wave flume used in these studies has dimension 1m by 1m by 50 m. We investigate the case for shallow water wave propagation on fixed water depth and for the case with variable depth (a linear bottom profile) for a slope of 1:100. A computer control-and-feedback system is used to generate the desired wave profiles. We generate both simple (only a few inverse scattering transform components) and complex wave forms (many IST components). We analyze the data using IST for both the KdV and extended KdV equations. We give evidence that both methods yield similar results for waves up to moderate amplitudes. At higher amplitudes only the extended equation yields consistent results. Waves are considered up to the highest wave (as discovered by Stokes which has the peaked form with subtended angle of 120 degrees).

STRONG INTERNAL WAVES IN THE COASTAL ZONE

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Tide-generated internal bores and solitons on shelf are known to be an ubiquitous phenomenon. A commonly accepted description of them is based on the Korteveg-de Vries equation or its generalizations. However, the solitons can be so strong that the use of the evolution equation needs a special consideration. This is the case for a recent experiment performed in the Northern part of the Pacific coast of the USA. Some of internal solitons generated by the tide were extremely strong: thermocline was depressed up to 30 m from its initial position at 5-7 m. To describe such events, we used different models. One of them is a well-known extension of the KdV by adding a qubic nonlinear term. Some peculiarities of strong soliton formation and soliton interaction for this equation are demonstrated. For a more realistic description, an exact equation for the long nonlinear-wave velocity (derived by D. E. Pelinovsky) was analysed (the dispersion term is still approximate). Along with the analytical consideration, a comparative numerical analysis of an initial pulse disintegration in frames of different models was performed. Comparison with observational data is also presented.

DYNAMICS OF SURFACE WAVE SPECTRA IN THE PRESENCE OF SWELL AND INTERNAL WAVES

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We analyze temporal variations of gravity wave spectra in a range from 0.03 Hz to about of 3 Hz measured with wire wave gauges performed by ETL in September, 1995. The following results are worth to be discussed. 1. A very long (10 to 15 s period) and intensive (amplitudes of up to 2.5 m) swell was observed. The frequency shifts in time towards shorter wave were observed, i.e., the wave is frequency-modulated. This allowed us to estimate a distance to the wave source. 2. Our results show that for wind speed between 5.5 m/s and 8.5m/s, the slope of the wind-wave frequency spectrum lies roughly between $\omega^{-3.4}$ and ω^{-4}. Comparison with the known model spectra (e.g., JONSWAP) shows that these spectra are not always equilibrium, and are probably affected by swell. 3. Some records were taken during the presence of very strong tidally-generated internal waves (groups of solitons). A significant growth of the wind-wave intensity in a range of 0.7-1.2 Hz after entering of the internal wave train was registered. Theoretical estimates suggest the role of "group synchronism" (phase velocity of internal waves is close to the group velocity of surface waves in this range).

GENERATION AND EVOLUTION OF INTERNAL WAVES IN THE NEW YORK BIGHT

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Numerous trains of soliton-like internal waves were measured in the New York Bight during the 1992 US/Russia Internal Wave Experiment. These data have been compared with the results of a nonlinear numerical model. It was shown that the internal waves are generated by the interaction of the barotropic tide with the shelf break. An internal onshore propagating shock is developed, which eventually decays into a packet of solitary internal waves through a process of nonlinear self-interaction. The model results are in a good agreement with observations.

LONG PERMANENT INTERNAL WAVES IN ROTATING FLUID: STUDY OF SOME LIMITING CASES

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In the shallow water assumption, we study permanent interfacial long waves.for some particular cases which are relevant in oceanographic conditions. The ocean is modelled as a two layer fluid in the f-plane approximation First we recall the asymptotic developments leading to the Ostrovsky equation in the weak rotation case. Then we assume that the density difference is small, and we study waves with either a small or a large amplitude. We show that for small amplitude waves a smaller density difference tends to increase rotation effects, and this result is supported by experimental data. Moreover, when looking for large amplitude waves, we find that new solutions appear when rotation tends to zero. Then the interface variations are elliptical funtions which are solutions of the following equation:

$$\frac{dh_2}{d\theta} = \pm f \frac{\sqrt{P_6(h_0(\theta))}}{R(h_0(\theta))}$$

where f is the Coriolis parameter, P_6 a sixth-order polynomial and R a rational function. Now if we consider that one of the layer is very thin, still with a small density gradient, then the interface variations are solutions of :

$$\frac{dh_1}{d\theta} = \pm f \frac{\sqrt{P_4(h_1(\theta))}}{R(h_1(\theta))}$$

where P_4 is a fourth-order polynomial. Thus we get a complete set of equations covering most of the practical cases that can be found in the ocean. We also performed experiments in the 13 m diameter rotating tank which supports our conclusions.

PROPAGATION OF SURFACE GRAVITY WAVES ON MODULATED SLOPING BOTTOMS

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The investigation of wave scattering by changes in seabed topography is of practical importance in oceanography. Quasi-sinusoidal sand bars formation outside the breaker zone has drawn interest since they are capable of partially reflecting incident waves.

Herein, both numerical and experimental works on wave reflection due to modulated sloping bottoms are reported. The numerical model is based on the full potential theory of linear gravity waves propagating on varying bottoms. The experiments are carried out in a glass-walled wave tank 10 m long, 30 cm wide and 50 cm deep.

For beds consisting of a superimposition of a constant slope and of a sinusoid, strong reflections are observed when the mean surface wave number is about half the bed wavenumber. The case of quasi-sinusoidal shapes related to the local surface wavenumber is presented and the role of the evanescent modes in the interference processes is demonstrated.

RESONANT EFFECTS IN THE WIND FLOW WITH VELOPAUSE OVER BOTTOM TOPOGRAPHY

S.N.Reznik, Yu.I.Troitskaya (Institute of Applied Physics Russian Academy of Sciences, 46, Ul'anov str., 603600, N.Novgorod, Russia)

Qualitative properties of wave drag of local bottom topography is studied for stratified shear flow, changing its direction with height, which models the wind with velopause in atmosphere. The wind, one component of which is uniform, but second has a constant shear,is considered. It is shown, that the critical layer(CL) for the waves, radiated by the obstacle, exist in the flow. The wave drag force appears to be the sum of the wave loses due to radiation of the waves of continuous spectrum, having the CL, and the waves of discrete spectrum, which does not have CL. Two types of topography are considered: long ridge and axial symmetric obstacle. Dependences of wave drag force on the main parameters(the Froud and Richardson numbers) is obtained.

The deformation of the flow due to resonant interaction with the waves, radiated by topography in velopause, is investigated. The wind, which direction depends on the height in the layer of finite size, over the plate with statistic-uniform field of perturbation, is considered. The equations for the components of average wind velocity are derived for small Froud numbers in kwasilinear approximation. It is shown, that the absolute value of wind velocity does not depend on time. It is found, that the equation for the angle, which define the direction of wind, is the equation of simple Riman waves. The deformation of the flow is defined by the average drag, exerted on the unit square of the plate.

RADIATION FORCES, EXERTING ON A POINT SOURCES, MOVING IN A STRATIFIED LIQUID

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Two components of radiation force, exerting on a sources, moving in the stratified media with constant speed are calculated. This force is due to the radiating of internal waves. One component of this force is opposite to velocity of the source, but second is perpendicular to the direction of moving. Second component is calculated for a first time. This results are extrapolated on the case of rotating media.

This work was supported by the RFBR

EFFECTS OF AN ASYMMETRIC FRICTION ON THE NONLINEAR EQUILIBRATION=20 OF A BAROCLINIC SYSTEM

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Following some recent linear and nonlinear studies, the effects of a vertical asymmetry in friction on the nonlinear equilibration of unstable baroclinic systems are examined. Most of the recent studies are related to the nonlinear dynamics of synoptic waves. Here we consider both "short" and "long" waves (in terms of their zonal wavelength). A classical two-layer quasi-geostrophic model in which dissipation occurs through top and bottom Ekman layers is used.

Nonlinear numerical results display a significant wave scale selection due to asymmetric friction. A traditional asymmetric friction (with the upper layer less viscous than the lower layer) leads to a nonlinear equilibration characterized by the emergence of "long" waves. With nontraditional asymmetric friction (with the lower layer less viscous than the upper layer) only "short" waves emerge. Sensitivity of these results to the variation of dissipation and forcing parameters values is examined. Emphasis is laid on the effects of asymmetric friction on the wave-wave and wave-mean flow interactions and their consequences on the wave scale selection.

MODELLING OF A GRAVITY CURRENT DOWN THE OCEANIC SLOPE

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Flow of a denser fluid down a sloping bottom in application to oceanic gravity currents is studied. Conducted laboratory experiments in a tilted tank with varying Reynolds and Froude numbers revealed different flow regimes: steady flow, undulated flow with formation of periodic vortex structures at the density interface, break up of the undulated flow and transition to turbulence. Numerical solution of the vorticity and density evolution equations of a stratified viscous fluid and also a stability analysis of parallel flows help to interpret the results of the laboratory experiments. Connection to the limiting cases of Kelvin-Helmholtz instability waves and hydraulically controlled roll waves is discussed.

ON THE INTERNAL WAVE – SHEAR FLOW RESONANCE IN SHALLOW WATER

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The work is concerned with long nonlinear internal waves interacting with a shear flow localized near the sea surface. The study is focused on the most intense *resonant* interaction occuring when the phase velocity of internal waves matches the flow velocity at the surface. The finite amplitude perturbations of the shear flow are considered as the vorticity waves, which enables us to treat the wave-flow resonance as the resonant wave-wave interaction between an internal gravity mode and the vorticity mode. Within the weakly-nonlinear long-wave approximation a system of evolution equations governing nonlinear dynamics of the waves in resonance is derived and an asymptotic solution to the basic equations is constructed. At the resonance the nonlinearity of the internal wave dynamics is due to the interaction with the vorticity mode, while the wave own nonlinearity proves to be negligible. Some non-trivial regimes of wave dynamics were found within the derived equations.

KINETIC EQUATION FOR ROSSBY WAVES IN MULTI-LAYER OCEAN

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Long-term evolution of baroclinic geophysical flows in the framework of weak beta-plane turbulence can be described in terms of Rossby wave resonant interactions. The sequence of kinetic equations (describing slow evolution of the energy spectrum of the barotropic and the baroclinic modes) is derived for the model ocean consisting of a finite number of non-mixing homogeneous layers. The main properties of these equations coincide with those for the barotropic and the two-layer models. They conserve energy and both the components of the wave impulse. The flow evolves towards a thermodynamically equilibrated final state. The latter consists of a zonal flow (with an arbitrary modal structure) combined with an essentially baroclinic wave field with the Raleygh-Jeans spectrum.
The equilibrated spectra are stable with respect to small disturbancies. Formally, there exists a set of stationary generalized solutions to the kinetic equations. These solutions correspond to wave systems propagating in a fixed direction or to sets of waves with equal p-wavenumbers $\kappa_p = \sqrt{\kappa^2 + a_p}$, where $\kappa = (k, l)$ is the wave vector and a_p^{-2} is the Rossby radius for the p-th mode. These spectra are unstable except those corresponding to rectilinear zonal flows.

GENERATION OF SUPERHARMONICS AND SUBHARMONICS BY SHOALING WAVES

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The phase averaged equation for the nonlinear evolution of shoaling waves, which was recently obtained by Agnon & Sheremet (1996), serves as the starting point. Their shoaling interaction function, **J**, is here significantly simplified through the assumption of parabolic bathimetries. Superharmonic generation of the second harmonic ($2\omega_o$), as a result of shoaling of a very narrow spectrum (with frequency ω_o); as well as subharmonic generation of long waves with frequency Ω, as a result of the interaction of two wave fields with very narrow spectra (around ω_0 and $\omega_0 + \Omega$), are studied. Analytical solutions for waves moving up a beach, or the sea-side slope of a submerged bar, are presented. The possible subsequent behavior on the shoreward slope of the bar is also discussed. In the most extreme conditions the superharmonic modes will attain half of the total energy flux, whereas the subharmonic modes will extract a much smaller fraction ($\approx 0.3\Omega/\omega_o$), of the total energy flux.

ESTIMATIONS of the NONLINEAR PROPERTIES of the INTERNAL WAVE FIELD in DIFFERENT REGIONS of the WORLD OCEAN

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Nonlinear effects are essential to internal waves overing to small speed of propagation, and nonlinear internal waves are observed very often. Most of the observations can be described within the theoretical model based on the Korteweg - de Vries equation and its modifications. Coefficients of this equation depend from the vertical profile of the Brunt-Vaisala frequency and shear flow. The measurements of the vertical structure of hydrological fields in different regions of the World Ocean are used for calculation of the coefficients of this equation which determine the speed of long wave propagation, dispersive and nonlinear parameters. Spatial and temporal variability of these characteristics are studied and geographical features of prognostic characteristics of the internal wave field are discussed. Results of the numerical simulation of the nonlinear internal wave transformation in oceanic regions with horizontal variability of density and shear flow are presented.

This work was supported by the grants from the RFBI (96-05-64108), INTAS (5500-969).

EFFECTS of CUBIC NONLINEARITY on the DYNAMICS of INTERNAL WAVES

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Traditionally, the nonlinear dynamics of long internal waves in shallow water is studied within the framework of the Korteweg-de Vries equation. The coefficient of the quadratic nonlinear term can be positive or negative depending on the vertical structure of the density field and the background shear flow. The effects of cubic nonlinear terms have received relatively less attention. It has been shown that the cubic term is negative for a two-layer model of the ocean stratification. In this paper we present results of the calculation of the coefficient of the cubic term for several forms of the Brunt-Vaisala frequency profile. It is found that this coefficient can be either positive or negative depending on the particular profile. Numerical simulation of the extended Korteweg- de Vries equation is used to demonstrate the role of these cubic effects on the evolution of internal waves.

This work was supported by the grants from the RFBI (96-05-64108), INTAS (5500-969).

ROSSBY WAVE IN A PENETRATIVE CONVECTION REGION

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A two-dimensional model of rotating fluid layer is considered. In the upper part of the layer a convection is excited due to heating from below. In the lower part of the layer the conditions of convective stability are realized, but convective motions penetrate into this region. Under usually employed conditions Rossby wave specified at the initial instant decays due to dissipation. Numerical simulations show that the inclusion of the influence of the Rossby wave on the convection conditions gives rise to modulation of convection and to realization of pumping mechanism for Rossby wave. This result is important for interpretation of many solar phenomena.

EFFECT OF WIND TURBULENT DRIFT FLOW ON THE WIND GROWTH RATE OF THE CENTIMETER SURFACE WAVES

Yu.I.Troitskaya (Institute of Applied Physics Russian Academy of Sciences, 46, Ul'anov str., 603600, N.Novgorod, Russia)

Effect of wind drift flow on the wind growth rate of the centimeter surface waves is studied. The coupled model of a turbulent air-water flow is employed based in the Reynolds equations expressed in curvilinear coordinates with one coordinate line coinciding with the air-water interface undulated by the wave. Comparison of results of calculation of wind wave growth rate within two different models is performed: i) the Prandtl mixing-length model, ii) the model of visco-elastic turbulence with the complex viscosity coefficient, which is similar to the model based on the "rapid-distortion" theory. Analysis of wave energy fluxes for the centimeter surface waves shows that in the air, profiles of these values are close in both models, but in the water they are sufficiently different, which determines sufficient difference in the wave growth rate calculated within these models. For weak and moderate winds (with the friction velocity less than 40 cm/c) the drift flow slightly affects the wind increment of the surface waves. For the wind friction velocity more than 60-65 cm/c this model predicts sharp increasing of the wind increment due to the Kelvin-Gelmgoltz instability. The wind growth rate of the centimeter surface wave calculated within the model of visco-elastic turbulence for hydrodynamically smooth regim of the wind flow over the water surface is in good agreement with the available laboratory experimental data. This work was supported by the grants INTAS-93-1373 and RFBR (project code 96-05-65128).

On the physics of upgradient momentum transport in unstable zonal jets

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We consider the instability of an arbitrary shaped zonal jet in a midlatitude β-plane channel within a two-layer quasi-geostrophic model. Depending on both the horizontal and vertical shear of the jet, it is susceptible to both barotropic and baroclinic instabilities. We calculate the linear stability boundaries numerically focussing on parameters as the jet width and the vertical shear. The weakly nonlinear evolution near criticality is shown to be governed by a complex Ginzburg-Landau equation. Solutions of this equations show how both the disturbances grow to finite amplitude as well as how the jet is modified by their nonlinear interaction. The inclusion of friction allows for a detailed analysis of this modification that leads to a description how the interaction of unstable modes induces an upgradient momentum transport and consequently sharpens and strengthens the jet. Application of these results to the Antarctic Circumpolar Current shows that upgradient momentum transport occurs in this case.

EDDY INTERACTIONS: AN ISOPYCNAL POTENTIAL VORTICITY DIAGNOSTICS.

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A 2 1/2-layer formulation of the Bleck and Boudra isopycnal coordinate model forced by a steady mass flux, was used to simulate a middepth intrusion of mass and the production of meddies. The model is configured in a rectangular basin confined by vertical walls, the mass forcing is represented as a side boundary condition and open conditions are imposed at downstream boundary. For a broad region of the nondimensional parameter values, the model solution reveals the presence of a complex flow field that contains filaments, meanders and eddies extended ver a large band of wavenumber spectrum. The present study is an effort to understand the non-linear coupling between high-frequency small-scale disturbances generated at the forced region and the low-frequency large-scale eddies in the interior domain. A diagnostics based on the low-frequency isopycnal potential vorticity equation was developed to describe the average effect of small-scale eddy fluxes on the mean pattern of large-amplitude structures, as they migrate downstream along a vertical wall. This study shows that high-frequency disturbances have an organized systematic effect over the large-scale structures, opposite to the downstream propagation effect by the large-scale flow.

MULTI-MODAL SOLITARY INTERNAL WAVES IN THE NEW YORK BIGHT

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R. D. CHAPMAN (Ocean Remote Sensing Group Applied Physics Laboratory, The Johns Hopkins University, Johns Hopkins Road, Laurel, MD 20723)

Observations of intense short internal waves on the shelf of the New York Bight indicate that while the waves are nonlinear in nature, their form is not consistent with the solution of the K-dV equation. A higher order nonlinear theory was developed which at second order provides a significant correction to the lowest-order K-dV solution. This theory has been applied to predict the shape, vertical structure, and velocities of observed strong internal waves. The agreement between observations and theory is substantially improved by the inclusion of the second order corrections. The theory was also applied to relatively weak waves to show that the second-order solution is not necessary for the description of weaker waves.

MASS TRANSPORT INDUCED BY LONG SURFACE WAVES IN A ROTATING OCEAN

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Wave-induced mass transport in a viscous rotating fluid is discussed using a Lagrangian description of motion. The hydrostatic approximation is made, and the wave field is taken to attenuate in space due to the effect of friction. Simulating the effect of wave-breaking at a beach, and the subsequent mass accumulation near the shore-line by an on-shore mean pressure gradient, the steady mass transport due to monochromatic swell propagating in the direction of the shore is computed. In particular, a pronounced along-shore mean drift to the left of the wave propagation direction (on the northern hemisphere) is found when the Ekman layer is thinner than the fluid layer. This result is discussed i relation to sediment transport in shallow water.

SURFACE WAVES AND INTERNAL WAVES IN A STRATIFIED LIQUID LAYER: RESULTS FROM A MODEL EXPERIMENTAL PROBLEM

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When a liquid absorbs another fluid its surface tension is altered. If the absorbed fluid lowers the surface tension, surface waves are generated when the concentration gradient of the fluid is beyond a certain threshold. This is one among the possibilities of exciting waves not as the result of an initial disturbance like in the usual generation of waves, but rather as a consequence of an instability due to an imposed steady or time-dependent constraint. If there is a strong stratification in the liquid internal waves are triggered. In our time-varying experiment we observe both types of waves. Here we present experimental results on wave trains in annular-ring containers. The surface waves show typical nonlinear solitonic properties, while the experimental results on the internal waves point to another type of nonlinear process (Eckhaus instability).

GENERAL NONLINEAR WATER WAVE MODEL FOR REMOTE SENSING IN THE COASTAL AND DEEP OCEAN

James M. Witting (Pennsylvania State University; State College, PA 16804, USA)

Accurate water wave theories have been developed that run fast for deep water waves without shear currents (e.g. West, et al 1987) and for shallow water waves (e.g. Witting, 1984). This paper describes a theory that goes on to: 1) combine the fast techniques into a single theory for both deep and shallow water, and 2) while still inviscid, permit irrotationality, and so to treat meaningful wave-current interactions. The model advances surface variables in time, using an exact set of diagnostic equations for inviscid flows. A relationship among these surface variables is required to close the mathematical system which involves the whole fluid. This model employs a series expansion in small parameters. Only fast algorithms are necessary for solely deep water (fast Fourier transforms) or shallow water (tridiagonal matrix solvers). The expansions are carried far enough to describe all nonlinear phenomena short of wave breaking.

NONLINEAR PROCESSES IN GEOPHYSICS (NP)

NP1.1/SE29 Scaling, multifractals and nonlinearity in solid Earth geophysics

Convener: Schmittbuhl, J.
Co-Conveners: Bak, P.; Herrmann, H.J.; Turcotte, D.L.

PARAMETRIC REZONANCE OF A LIQUID DROPLET OSCILLATION IN A FILAMENT CAPILLARY OF A POROUS MEDIUM.

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In our report we have briefly analysed the physical process of solitary water dropplet parametric oscillation in filament capillary of porous geomaterial under incedent P seismic wave. The estimation is received of nonlinear parametric oscillations and the conditions of optimal excitation is clarified. The problem is interesting in a seismic action to increase of a debite productivity of boreholes filled with an oil and gas.

INTERFACE EFFECTS AND INTERMITTENCY IN BLOCK SLIDINGS

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M.A.F. Gomes (Departamento de Física, UFPE, 50670-901, Recife, PE, Brazil)

It is shown that the measured length distribution of slidings of solid blocks on an incline in response to small perturbations obeys nontrivial scaling laws which depends on the *dimensionality* of the interface but are to a large extent independent of material and angle of inclination. These scaling laws are reminiscent of the Gutenberg-Richter law and are more sharply defined than the analogous distributions obtained in somewhat related experiments involving avalanches in sandpiles and liquids performed in the last few years by a number of authors. Furthermore, the average time interval τ between these block slidings or "blockquakes" scales with the length L of the blocks as $\tau \sim L^{-\alpha}$, $\alpha = 0.56 \pm 0.02$, in agreement with the law governing the average time between earthquakes on faults with characteristic size L.

ANALYSIS OF THE TEMPORAL OCCURRENCE OF SEISMICITY AT DECEPTION ISLAND (ANTARCTICA). A NONLINEAR APPROACH

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Deception Island is characterized by small magnitude local events with constant energy flux and very low stress drop. To obtain information about its origin, an interevent time series of 546 events, corresponding to an observational period of two month, has been analyzed. From a statistical point of view, data satisfies a Weibull distribution and presents clustering. A rescaled range analysis reveals that data are not independent, {\it i.e.} have memory, and the correlation dimension saturates at 2.2; as a consequence, the system can be modeled as a non-linear iterative equation with three degrees of freedom that presents chaotic behavior. Taking into account that the average interevent time is of the order of 130 minutes, too short to be due to only tectonic activity, the above results indicate that some other mechanism may coexist with the regional tectonic one. According to several geological and geophysical observations we suggest that most of the local events may be originated by pressure waves generated by a sudden change of phase, of sea and fresh water infiltrated into the main fractures and faults and also from shallow and confined water-saturated layers.

UNIVERSAL MULTIFRACTAL ANALYSIS OF SURFASES OBTAINED BY BREAKAGE OF BASALT SPECIMENS

A.V.Chygyrynsky (Department of Material's Resistance, Ukrainian Agricultural University, Kiev, Ukraine)

A series of laboratory measurements of classical parameters considered by material's resistance theory, such as loss of strength and breakage point, of basalt specimens in bending and in tension were carried out in Department of Material's Resistance (Ukrainian Agricultural University). The examination of different surfaces obtained by breakage of test specimens were performed with the help of universal multifractals (Schertzer, Lovejoy, 1987), determining their Levy index (α) of multifractality and critical order of first order phase transition q_D which leads to the appearance of non-classical Self Organized Criticality. We compare obtained result with those are presented in (Shmittbuhl et al., 1995).

QUASI-STATIC CRACK PROPAGATION IN HETEROGENEOUS MEDIA

Deniz Ertas, Sharad Ramanathan and Daniel S. Fisher (Lyman Laboratory of Physics, Harvard University, Cambridge, MA 02138, USA)

The dynamics of a single crack moving through a heterogeneous medium is studied in the quasi-static approximation. Equations of motion for the crack front are formulated and the resulting scaling behaviour analyzed. In a model scalar system and for mode III (tearing) cracks, the crack surface is found to be self affine with a roughness exponent of $\zeta = 1/2$. However, in the usual experimental case of mode I (tensile) cracks, local mode preference causes the crack surface to be only logarithmically rough, quite unlike those seen in experiments. The effects of residual stresses are considered and found, potentially, to lead to increased crack surface roughness. Nevertheless, it appears likely that elastic wave propagation effects may be needed to explain the very rough crack surfaces observed experimentally.

DYNAMICS OF SOLITARY RELAXATIONS IN AN EXPERIMENTAL BURRIDGE-KNOPOFF LIKE SYSTEM

J. Galeano (EUITAgricolas, UPM, Ciudad Universitaria, Madrid Spain)
P. Espanol and M.A. Rubio (Dpto. Fisica Fundamental, UNED, Apdo Correos 60141, 28080 Madrid, Spain)

We report on experiments on the dynamical behavior in a model system for earthquakes and stick-slip dynamics. In the experiments, shear is imposed on a transparent gel in between two coaxial circular cylinders [1]. The stress relaxations are investigated locally by means of photoelastic techniques and several dynamical regimes are found.

We will focus on the propagating relaxations (PR) regime where one or more localized regions slip simultaneously. The velocities of the PR's are 100 to 1000 times larger than the pulling speed. Moreover, their velocities are proportional to the pulling speed and the rigidity of the gel and inversely proportional to the number of PR's present in the system.

We will present numerical simulations of a Burridge-Knopoff model with Coulomb friction that display stable subsonic PR's exhibiting similar behavior. In the continuum limit subsonic propagations are forbidden but stable subsonic PR's involving only few blocks can be constructed. This suggests that the experiment has a *discrete-like* behavior and we will provide some hints on the physical origin of this effect.

[1] M.A. Rubio and J. Galeano, Phys. Rev. E, **50**, 1000 (1994)

EARTHQUAKE STATISTICS IN SIMPLE MODELS OF HETEROGENEOUS FAULT ZONES

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Observations have shown that earthquakes exhibit apparently universal scaling of the rupture size distributions and related quantities. We study simple models for ruptures along a heterogeneous earthquake fault zone with quasistatic stress transfer, in particular focusing on the interplay between the roles of disorder and long range elastic interactions. It is found that there is a critical point in a class of such models whose properties might underly the observed power law scaling of real earthquake statistics. We examine the effects of both the amount of disorder in the fault properties and finite fault size effects, on earthquake sequences and the distribution of event magnitudes. The studies employ mean-field theory and other analytic methods as well as three-dimensional simulations. Some effects of dynamic stress transfer via seismic waves have also been explored.

MULTI-SCALE IMAGE ANALYSIS : THE NORMALISED OPTIMISED ANISOTROPIC WAVELET COEFFICIENT (NOAWC) METHOD.

P. Gaillot, J. Darrozes, G. Ouillon, M. de Saint Blanquat, J.L. Bouchez (UMR 5563 CNRS - 38 rue des 36 ponts F-31400 Toulouse)

Investigation of complex spatial organisations, such as rock fabric, necessitates recognition and understanding of a number of physical processes acting simultaneously at different scales. Finding out the part taken by each spatial organisation, according to its characteristic scale, is an effective way to analyse such systems.

This approach can be automatically performed by the Normalised Optimised Anisotropic Wavelet Coefficient method (NOAWC) which allows to decipher signals where information of different scales are combined.

Multi-scale rock fabric analysis using the NOAWC method leads to recognise and quantify (size, shape anisotropy, orientation and location) the different levels of mineral organisation : (i) the mineral, (ii) the spatial organisation of minerals or texture, (iii) the spatial variation of texture leading to identification of connex entities as, for example, clusters of grains, and finally (iv) the spatial distribution of the connex entities or structure, such as alignments of clusters.

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FRACTAL DIMENSION OF MAGNETIC SIGNALS:COMPUTING ALGORITHMS

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ABSTRACT
In previous works we studied fractal character of marine measuring networks, in which total Earth Magnetic Field (E.M.F.) is sampled with a moving ship, in other words, without fixed position (kinematic GPS). We computed , by Grassberger and Procaccia Method, the value of Fractal Dimension (FD) of several measuring networks giving for all of them values near 1.80,it seems to be a typical value. In the first part of this work, we introduce four algorithms related to corresponding methods for fractal dimension evaluation. In fact, computing method for F. D. evaluation depends by some properties (self-similarity, self-affinity,etc.)of points distribution. The algorithms were tested on fractal synthetic planar curves. In the second part we evaluete fractal properties of

FRACTAL GEOMETRY AND EARTHQUAKES STATISTICS

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We present a Self-affine Asperity Model (SAM) for the seismicity that mimics the fault friction by means of two fractional Brownian profiles (fBm) that slide one over the other. An earthquake occurs when there is an overlap of the two profiles representing the two fault faces and its energy is assumed proportional to the overlap surface.
The SAM exhibits the Gutenberg-Richter law with an exponent β related to the roughness index of the profiles. Apart from being analytically treatable, the model exhibits a non-trivial clustering in the spatio-temporal distribution of epicenters that strongly resembles the experimentally observed one. A generalized and more realistic version of the model exhibits the Omori scaling for the distribution of the aftershocks.
The SAM lies in a different perspective with respect to usual models for seismicity. In this case, in fact, the critical behaviour is not Self-Organized but stems from the fractal geometry of the faults, which, on its turn, is supposed to to arise as a consequence of geological processes on very long time scales with respect to the seismic dynamics. The explicit introduction of the fault geometry, as an active element of this complex phenomenology, represents the real novelty of our approach.

CHAOS IN GEODYNAMO AND PRECISION OF REAL PALEOMAGNETIC DATA.

Pavel Jasonov (Faculty of Physics, Kazan University, Kazan, 420008, Russia).

The time series of geomagnetic field reversals (GFR) are very irregular, but number of well dated reversals in Earth's history amount to not more than 300. This is too few for correct determination of statistical properties of the reversal process, and it is only possible to determine intervals where these parameters change. Time series generated by Rikitake disc dynamo models have been calculated for comparation with real geomagnetic field reversals (GFR) time series. There are some important differences between the real and model data, such as some error in the time scales of the real data. A number of model time series have been constructed taking into account these problems. The limits of the change in statistical properties of the model data (types and parameters of distribution, correlation dimension) have been obtained. Correlation dimension strongly depends upon precision of determination of reversal moments in time series, generated by dynamo model. This fact shows that behavior of geomagnetic field could be described by the system with low correlation dimension, such as disc dynamo model.

FINITE-SIZE SCALING OF CONDUCTIVITY IN FRACTAL GETEROGENEOUS MEDIUM

S. S. Krylov and N. Y. Bobrov (Institute of Physics, St. Petersburg State University, St. Petersburg, Russia 198904)

When the concentration of high-conductive component in heterogeneous medium approaches to critical value (percolation threshold), such a medium becomes a geometric fractal. Within fractal area average electrical characteristics (i.e. conductivity, dielectric constant, relaxation time) obey finite-size scaling lows. This effect can take place both for microscale (the case of porosity) and for macroscale (geological features). In the last case one can to investigate the scaling by different electromagnetic arrays used in electrical prospecting. There have been carried out a special experiments in the permafrost region over the layer of frozen saline clay possessing high ice-content. The investigations revealed the fractal structure of frozen rocks, which contain segregated ice veins and sedges. This can be a result of self-organized criticality state, connected with temperature phase transition in permafrost. The results of investigations allow to evaluate scaling exponent and choose the model of frozen rock structure.

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CONNECTION OF FRACTAL PROPERTIES AND SCALING OF THE MAGNETIC FIELD REVERSALS WITH THE REGIME CHANGE OF THE EARTH'S CORE CONVECTION

V. V. Kuznetsov and **V. V. Kuznetsov** (Institute of Geophysics, University av.,3, Novosibirsk 630090, Russia)

It is shown by us that the discovered earlier fractal properties and the scaling of the Earth's magnetic field reversals can be explained by the convection regime change in the outer core. The model suggested by us is based on the following: 1)the analysis of the splitting functions for 11S4 modes shows that in the outer core there are 12 convected cells of the tesseral harmonic T3/4 type; 2)it is suggested that the radius of the Earth's outer core did not change during the evolution, whereas the radius of the inner core has decreased; 3)with increasing the outer core thickness. number of the convecting cells formed in it was always decreasing; 4)the Earth's magnetic field changed its polarity, when the convection regime has changed, and its polarity did not change, when the convection was steady; 5)the convecting cells have the same fractal structure and they belong to the same versatility class. The calculated durations of the steady convection and the periods of changing its structure were compared with the periods of the Earth's magnetic field reversals. Their large community gives grounds to consider that this model is identical to the nature of the Earth's magnetic fiekd polarity change.

SELF-ORGANIZATION OF ENSEMBLE OF THE CRACKS EMITING THE SOUND

V. V. Kuznetsov and **V. V. Kuznetsov** (Institute of Geophysics, University av.,3, Novosibirsk 630090, Russia)

This paper proposes the model of the self-organization of cracks arising in the rock (granite) under a load. This model is based on using the presumed effect of acoustic wave interaction between the cracks being formed. This model uses some solutions of Fokker-Planck's equation. In this paper the results of laboratory experiments are explained in which such phenomena were found as the spontaneous increase of intensity of acoustic emission, its the spatial and temporal clastering and the formation of the fractal structure under the constant and smoothly varying load on the rocks samples. On the basis of this model, the attempt is made to elucidate the earthquake nature.

SCALING LAWS AND NON-LINEARITY IN GEOELECTRICAL PRECURSORY SIGNALS AND IN SEISMICITY ON SOUTHERN APENNINE CHAIN (ITALY)

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M. Macchiato (Dip di Scienze Fisiche, Università Federico II, Naples, Italy)
C. Serio (Dip. di Ingegneria e Fisica dell'Ambiente, Università della Basilicata, Potenza, Italy)

In this work we propose the self-organized criticality as a powerful tool to describe the complicate correlation between electrical precursory phenomena and seismicity in a selected area of the Southern Apennine chain. The appearance of self organized criticality is signed by spatial and temporal scaling laws in the precursory phenomena of electrical nature and in seismicity patterns. The space and time dynamics of the electrical signals is characterized by rich scaling properties that are typical of a wide class of fractional Brownian processes. Furthermore flicker noises are detected from the analysis of earthquake sequences and, at the spatial scale, a self-similar structure in the epicentre aggregate is determined by the estimation of its fractal dimension. A correlation between the main dynamic features of the earthquake sequences and the local complexity of the seismotectonic environment is carried out. Our findings bring us insight the inner dynamics of the geophysical process under study: an estimate of the number of degrees of freedom of the dynamical system governing the generation of the electrical precursory phenomena is obtained. All the possible implications with the earthquake prediction problem are discussed.

ANALYSIS OF KTB LOG DATA: MAINLY $\frac{1}{f}$-NOISE IN CRUSTAL PROPERTIES

Leonardi, S. and Kümpel, H.-J. (Geological Institute - Applied Geophysics, Nussallee 8, D-53115 Bonn, Germany)

Small scale variations of geophysical borehole data reflect the geological inhomogeneities in the Earth's crust, i.e. its petrologic-mineralogic and structural organization, and bear meaningful information of past dynamical processes and evolution. In this work geophysical log data from the pilot hole (4000 m deep) and the main hole (9101 m deep) of the German Continental Deep Drilling Program (KTB) were analyzed for their statistical properties. The diversity of the log data (density, porosity, electric resistivity, seismic velocity, magnetic susceptibility and γ-ray) as well as their high resolution (6 inches sampling rate, i.e. 72,000 to 84,000 values per parameter) stand for a high significance of the results. Spectral and rescaled range analyses were applied to each data series. The results show that the spectral exponents b fall in the interval $-1.5 < b < -0.5$ and the Hurst exponents H range between 0.6 and 0.8. The best stochastic model expressing the small crustal heterogeneities is thus given by $\frac{1}{f}$-noise, with scaling behaviour from metres to thousands of metres. Further studies demonstrate that the statistical properties of the physical parameters do not change significantly with depth. $\frac{1}{f}$-noise and the related fractal character hint at a possible self-organized criticality in the dynamics of the Earth's crust.

SELF-ORGANIZED CRITICALITY. PARADIGM AND DESCRIPTION.

G.G.Malinetskii and A.V.Podlazov (Keldysh Institute of Applied Mathematics, Miusskaja pl. 4, 125047, Moscow, Russia)

Dynamics of many complex systems demonstrates power-law probability distributions. This phenomenon is regarded as self-organized criticality. Earthquakes gives us an example of SOC in the form of Gutenberg-Richter relation between quantity of earthquakes and theirs energy $N(E) \propto E^{-\alpha}$. Analysis of SOC from the point of view of branching processes theory is performed. Any branching process with independent particles can be described by universal law of "minus three seconds" $p(x) \propto x^{-3/2} e^{-\beta x}$. For branching processes with an interaction simulation gives a formula $p(x) \propto x^{-\alpha} e^{-\beta x}$, where α varies from 0 to 3/2 while interaction strength being changed. This enables one to observe a transition from the critical to non-critical behavior. So the criticality is a quantitative phenomenon and needs of a numerical measure. A mean value gives no information about big events and often could not be found from observations. Parameters of distribution have also a lot of shortcomings. We propose a new convenient statistical characteristic $Scx = \overline{x^2}/\overline{x}$ named scale. It determines the size of significant events occurring in system. Presence of two characteristic sizes (scale and average) is a fingerprint of criticality and their ratio represents its measure. SOC-models with open boundary conditions are quite difficult for studying. So we introduce a new closed model. It combines essential lucidity with opportunity to look after the whole spectrum of the properties of self-organized criticality both numerically and analytically.

DYNAMICALLY ACCESSIBLE OPTIMA IN NATURAL FRACTAL PATTERNS

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A. Rinaldo (Istituto di Idraulica, Università di Padova, I-35131 Padova, Italy)

Nonlinear self-organized processes have been suggested to be at work in the shap ing of natural landforms and to be responsible for the recurrent features observ ed in river networks. In particular it has been observed that these systems evol ve towards stab le minima of total energy dissipation. This is expressed in the concept of feasi ble optimality, which refers to the fact that the stationary states, and their f ractal and statistical characters, accessible to open, dissipative systems with many degrees of freedom are critically determined by their boundary conditions.

We study an example of such a system, made up of N metal balls free to move w ithin a medium of low electrical conductivity where charges are injected from ou tside. When grounded, the system self-organizes into aggregates which have been observed experimentally and possess scaling features. An exact variational principle of global nature is defined for the underlying Poisson problem and stable stationary states are at a minimum of total energy dissipation and total potential energy. Our numerical simulations are consistent with observatio ns and we find a finite-size scaling law that correctly captures the fractal cha racters of the observed structure.

NUMERICAL SIMULATION OF BLOCK-STRUCTURE DYNAMICS: THE MODEL WITH 3D MOVEMENTS OF BLOCKS

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A. Soloviev (International Institute for Earthquake Prediction Theory and Mathematical Geophysics, Moscow 113556, Russia)

The block model of lithosphere dynamics with 3D movements of blocks is presented. A seismically active region is considered as a system of absolutely rigid blocks separated by infinitely thin plane faults. The system of blocks moves as a consequence of prescribed 3D motion of the boundary blocks and the underlying medium. Displacements of the blocks are determined in such a way that the system is in quasistatic equilibrium state. Block interaction along the faults is viscous-elastic while the stress is below a certain strength level. When the level is exceeded for a part of some fault a stress-drop (a failure) occurs in accordance with the dry friction model. The failures represent earthquakes. As a result of numerical simulation a synthetic earthquake catalog is produced. Both simple enough block structures and the structure which approximates the main tectonic elements of the Vrancea (Romania) region are tested to find the existence of premonitory patterns and features detected in real catalogs. The frequency-magnitude relations (Gutenberg-Richter curves) and the space distribution of epicenters are analyzed for the synthetic catalogs. The software designed is oriented to the use of multiprocessor computational complex.

The work was supported by the International Science and Technology Center (Moscow, Russia, Project #008-94).

USING FRACTAL AND EUCLIDEAN PORE DISTRIBUTIONS FOR MODELLING COMPRESSIBILITY IN POROUS ROCKS

J.S. Mendoza (Dept. Earth Sciences. Simon Bolivar University, Valle de Sartenejas, Edo. Miranda. Venezuela)

In this study we present a topological scheme for the pore space that can be used to explain the observed changes in porosity and the compressibility in porous rocks. In the model, porosity and the compressibility are computed by a boundary elements technique. Only a few pore shapes are considered, because we are interested in identifying which geometries are responsible for the main trend observed in the compressibility and the porosity, rather than fitting the data with a high degree of precision. Also, a forward model is used to simulate the changes in porosity and the compressibility and therefore the process becomes unmanageable when the number of shapes increases. We found that certain proportion of euclidean and fractal pores can account for the observed changes. The euclidean pores are used to describe the large amount of porosity, while the fractal shapes account for the large changes in the compressibility. On this way, we have constructed a model for the pore space that can serve as a starting point to compute other petrophysical parameters in porous rocks.

FRACTAL AND MULTIFRACTAL ANALYSIS OF THE MIXING IN MANTLE CONVECTION

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Fractal and multifractal analysis was performed on a data set of convective mixing for Newtonian and Non-Newtonian rheologies. Two data sets were analyzed, the images of the passive scalar field and of the passive marker-chains. The scalar field variable represented the vertical position of fluid particles at t=0, the marker-chain corresponded to the shape of the initially horizontal line of particles at a fixed depth at t=0. Box counting technique was employed to determine the temporal evolution of the fractal dimension D for a range of scales and of the multifractal spectra D(q) and f(a). As a result, the subranges where the images of mixing exhibit fractal and multifractal properties were determined.

FRACTAL RIVER NETWORKS: SELF-ORGANIZED FEASIBLE OPTIMA

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A. Maritan, M. Marani, R. Rigon, I. Rodriguez-Iturbe

A complex optimization problem related to the evolution of fluvial networks shows signs of self-organized criticality. It is fortunate that in this case key statistical features of the global optima are exactly known and extensive experimental observations are available. We show that imperfect optimal search procedures yield local optima statistically indistinguishable from those observed in nature and quite different from the global solutions. Instead, more refined annealing procedures achieve optimal states closer to the actual ground state but with significant departures from natural structures. We suggest that the dynamic, self-organized adaptation of the fluvial landscape to the geological and climatic environment corresponds to the settling of optimal structures into suboptimal niches of their fitness landscape and that the diversity implicit in feasible optimality may apply in cases of general interest. Thus natural fractal structures in the fluvial landscape are dynamically accessible, self-organized optimal states where evolution can settle in a stable manner. Such relative stability is achieved with respect to perturbations and is nonetheless reminiscent if the dynamic history, including an imprinting of its initial conditions and long-lived signatures of boundary conditions, here surrogating geologic constraints.

MULTIFRACTAL ANALYSIS OF DIPMETER WELL LOGS FOR CHARACTERIZATION OF GEOLOGICAL STRUCTURES

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We use multifractal analysis as a geostatistical tool for the characterisation of microresistivity signals produced by dipmeter well-logging tools. The signal is divided into segments of fixed length. For each segment, several texture indices characterizing the irregularity of the microresistivity signal are calculated. Plotted as a function of depths, these texture indices form what we call texture logs. We show that these texture logs can be used to distinguish geological lithofacies differing in their degree of heterogeneity.

SCALING POWER SPECTRUM OF POTENTIAL FIELDS: INDIVIDUALIZATION OF FACTORS WHICH INFLUENCE THE SCALING EXPONENT.

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The spectral decay properties of potential fields are studied to identify the factors which can influence the corresponding scaling exponents. Synthetic models with characteristics which are intermediate between Naidu's and Spector and Grant's models, (e.g.: magnetisation sources distributions which are white random at a scale greater than the field sampling interval ; single homogeneous body, intruded into a random white source distribution), produce fields whose spectral scaling exponents can assume values in the fractal range. We show also that the scaling exponent of continuous synthetic signals is strongly influenced by their shapes. Power spectra of asymmetrical signals and signals which exhibit sharp features in the time domain, are characterised by scaling exponents which belong to the fractal range. Since the scaling exponent of the field can assume values in the fractal range even if the sources are not fractal, the analysis of the field power spectrum is not sufficient to assert the fractal nature of the source. As a necessary condition we propose to analyse also the field phase spectra because they must be random for truly fractal source distributions.

WHY DO EARTHQUAKES STOP?

J.B. Rundle and S. Gross (Dept. of Geol. Sci. & CIRES, CB 216, University of Colorado, Boulder, CO, 80309, USA)
W. Klein (Dept. of Physics, Boston University, Boston, MA 02215,USA)

We address the basic problem of why an earthquake of a given magnitude ceases to extend. The paradox inherent in this fundamental problem arises from the fact that as an earthquake increases in areal extent, it tends to increasingly concentrate stress at the crack tip. Because the stress intensity factor increases as the crack grows, it would seem to be increasingly difficult for the rupture to experience arrest. The resolution of this question is usually tied to the qualitative idea that the difference $\sigma^F(x)$ - $\sigma(x)$ between classical failure strength $\sigma^F(x)$ and current stress on the fault $\sigma(x)$ varies in space, and that the growing rupture eventually encounters regions where difference between the strength and the stress is large enough to inhibit further growth. We adopt this basic picture and use it to construct a theory of Stochastic Fracture Mechanics. In this idea, extension of a shear crack depends on the existence of spatial correlations in $\sigma^F(x)$ - $\sigma(x)$. In this talk, We present theory and simulation results that support this approach.

TRAVELING DENSITY WAVE MODEL FOR EARTHQUAKES

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The discovery that simple meanfield earthquake models are associated with an energy functional (JBR et al., *Phys. Rev. Lett.*, 74, 1658, 1995) prompts us to propose the "Traveling Density Wave" model for earthquakes (JBR et al., *Phys. Rev. Lett.*, 76, 4285, 1996). In this nonequilibrium model, the physics is obtained from a Lyapunov functional, which plays the same role as an equilibrium free energy functional. The Lyapunov functional is constructed by assuming that the static force balance is the Euler-Lagrange equation of a functional potential. The equations describing the evolution of sliding on the surface are then obtained by 1) functional differentiation and 2) the requirement that the system evolve continuously toward a state of greater stability (lower energy). Abrasion and wearing of the surface are modeled as a random variation in the cohesive surface energy. A variety of phenomena can be predicted that have been verified in numerical simulations and observed field data.

LOCAL SCALING OF POTENTIAL FIELDS FOR THE ESTIMATION OF DEPTHS AND STRUCTURAL INDICES OF THE MULTIFRACTALLY DISTRIBUTED SOURCES : THEORY, SYNTHETICS, AND APPLICATIONS TO AEROMAGNETIC DATA

P. Sailhac and A. Galdeano (Institut de Physique du Globe, 4 place Jussieu, 75252 Paris 05, France)

We propose a method to characterize the supposed multifractal spatial distributions of the gravity and geomagnetic potential-field anomaly sources. The Maus and Dimri (1995) equation for the scaling behaviour of the Fourier power spectrum is generalized for the local scaling behaviour of the cover-thickness measure. By the way, the analysis yields to the mapping of local estimators of the depth and scaling exponent of the sources. We discuss the intrinsic link between this scaling exponent (Hölder exponent), and the structural index used in analytic techniques such as Euler deconvolution.
Tests on synthetic signals, then on aeromagnetic data of North Algeria illustrate the method. Typically, this can be used for high resolution data as a tool to build a priori models before inversion.

QUASISTATIC RUPTURE PROPAGATION: EFFECT OF PINNING

J. Schmittbuhl (Laboratoire de Géologie, École Normale Supérieure, Paris)
J. P. Vilotte (Département de sismologie, Institut de Physique du Globe,Paris)

We develop a discrete quasistatic model of a rupture propagation along an heterogeneous plane under an anti-plane loading. The stress field along the rupture front is computed by using a pertubation approach proposed by Rice. It includes non local interactions resulting from the bulk elasticity of the medium. Heterogeneities along the rupture plane cause fluctuations of the local threshold stress. We study the rupture between two rough fractured surface by considering spatial long range correlations of the threshold stresses. Indeed, fractured surfaces are self-affine and contact between them provide a correlated stress field. During the propagation, the scaling invariance of the front shape is studied. Transient and permanent regimes are characterized. Macro-scale friction laws are obtained from the relationship between the estimate of the external load and the average position of the rupture front.

MULTIFRACTALITY OF FAULT SYSTEM OF CAUCASUS

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Geometry of active faults of Caucasus was investigated by the help of methods of computer graphics. Maps of faults were reproduced on a computer screen what quantized the trajectories of faults and transformed them into 2-D sets of pixels. It is shown that these sets can support the multifractal measures. The sampling estimations of $f(a)$-spectra for such measures are calculated. Singularity indices in concrete points of multifractal fields were computed by the help of algorithm of wavelet transform. The distribution of singularity indices under practically achievable resolution was compared with spatial distribution of earthquake epicentres of Caucasus. In the regions of diffused seismicity the inverse correlational relationship is revealed between the probability of appearance of the epicentre of earthquake with $3\leq M\leq 7$ and the value of singularity index of multifractal measure characterizing the fault field in the same point.

RIVER MEANDERING AS A SELF-ORGANIZATION PROCESS

Hans-Henrik Stølum (Department of Earth Sciences, University of Cambridge, Downing Street, Cambridge CB2 3EQ, UK)

Simulations of freely meandering rivers and empirical data show that the meandering process self-organizes the river planform into a critical state characterized by fractal planform geometry and a mean sinuosity of π. The meandering process oscillates in space and time between a state where the river planform is ordered and one where it is chaotic. Clusters of river cutoffs tend to cause a transition between these two states and force the system into stationary fluctuations around the critical state. Comparison of the simulation result and free meandering rivers in nature, in terms of scaling statistics and mean sinuosity, yields close correspondence. This confirms that free meandering rivers are in a state of self-organized criticality.

ON DYNAMICAL ANALYSIS OF THE MAIN LITOSPHERIC PARAMETERS IN THE WHOLE TERRITORY OF HUNGARY

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The aim of our paper is a first estimation of the dynamical,as well as the non-linear behaviour of litospheric parameters in the territory of Hungary.
In this purpose we used the values of velocity of recent vertical movements.In contrast to "time-series",our data form a "coordinate-series" and instead of time-delay we used "spatial-shift" which means coordinate-variation "step by step".We computed this series for the 934 values,corresponding to 934 (measurement-and interpolated) grid points and structural-functions were also calculated.The scaling parameter **p** was varyied between **1** and **10**.We stated that in our case the variations of **scaling exponent s(p)** are between 0.2669 and 1.9710 and the corresponding **fractal dimensions D(p)** are between 3.7467 and 0.5073,the average of these values are 0.7921 and 1.2615,respectively.Our preliminary conclusion is that the investigated system (with special regard to vertical-velocity) has small dimension (degree of freedom) and means a deterministic chaos.

FRACTAL TREES WITH SIDE BRANCHING

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Classic studies of fractal trees have evolved from the Horton and Straeler classifications of drainage networks. Two-first order streams combine to form a second-order stream, two second-order streams combine to form a third-order stream, etc. Actual stream networks, however, also involve side branching. Tokanaga devised a matrix formulation to quantify side branching. The number of first-order streams that combine to form second-order streams is denoted N_{11} but N_{12} is the number of first-order streams that join second order streams, N_{13} is the number of first-order streams that join third-order streams, etc. Tokanaga further argued that in terms of branching ratios it was a good approximation to take $N_{12}/N_2 = N_{23}/N_3 =$ ... etc., $N_{13}/N_3 = N_{24}/N_4 =$..., etc. Horton's law that N_i/N_{i+1} = constant and r_{i+1}/r_i = constant define a constant fractal dimension. Tokanaga's approach defines an improved taxonomy of fractal trees. Drainage networks have been shown to satisfy this extended self-similarity, DLA clusters also satisfy the same self-similarity. Space filling two-dimensional and three-dimensional constructions are given both with and without side branching.

GAS BUBBLES DYNAMICS AS ORIGIN OF SHALLOW VOLCANIC TREMOR AT STROMBOLI VOLCANO

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The seismic activity of Stromboli is analyzed from records of infrasonic and tremor signals. The infrasonic signals have been decomposed into two distinct series: inter-event time between impulses and their relative amplitudes. Tremor time series and the inter-event time series have been analyzed with the classical methodology (histograms, autocorrelation and running mean test) as well as with the use of nonlinear methods (Hurts exponent and correlation dimension) and we have found that tremor ans inter-event time share the same characteristics: they are related to a system with memory and cannot be modeled through a nonlinear low dimensional chaotic system. The infrasonic impulses have can be associated with a bubble, which suffers a decompression when enters into a magmatic conduct. This decompression firts travels through the magma, and then to the surface through a stratified media, where it is recorded. A superposition of bubbles gives rise to a tremor. By means of Haskell matrix method, and using the interevent time and amplitude distribution as obtained from the infrasonic time series analysis, synthetic tremors have been generated and compared to reco rded ones: they are very similar. This similarity suggest that, at least for Stromboli, the origin of the tremor ant its spectral structure that propagates through a highly inhomogeneous stratified medium.

PHYSICAL ORIGIN OF SELF-SIMILARITY IN FLUVIAL TOPOGRAPHY

D. Veneziano, J.D. Niemann, G. Tucker, R.L. Bras, F. Colaiori, and A. Flammini (Dept. of Civil and Environmental Engineering, MIT, Cambridge, MA, USA)

The scaling laws of fluvial topography reflect a basic self-similarity property whose nature and physical origin are not well understood. We analyze the symmetries of fluvial topography and conclude that, if elevation $h(x,y,t)$ is self-similar, then it should satisfy $\{h(x_1,y_1,t) - h(x_2,y_2,t)\}|_A =^d r^H\{h(rx_1,ry_1,t) - h(rx_2,ry_2,t)\}|_{r^2A}$ where (x,y) are geographical coordinates relative to the main stream source, $|_A$ refers to a sub-basin of area A with outlet on the main stream, and $=^d$ means equality of all finite-dimensional distributions. This condition should hold for some real H and any positive r and A. Concerning the physical origin of self-similarity, we examine whether topographies that satisfy the above condition can be stationary solutions of a wide class of dynamic evolution models, the simplest of which has the form $\partial h(x,y,t)/\partial t = U(t) - \beta(z)A^m(x,y,t)S^n(x,y,t)$, where U is uplift rate, $z(x,y,t)$ is depth in the rock column, β is an erosivity coefficient, A is contributing area, S is slope, and m and n are parameters. One result we obtain is that, if $n = 2m$, $U(t)$ is any stationary process, and $\beta(z)$ is any homogeneous process, then $h(x,y,t)$ may approach a stationary configuration that is self-similar in the sense above with $H = 0$. The relation $n = 2m$ and the value $H = 0$ are supported by much theoretical and empirical evidence. The fact that this result is found under any homogeneous erosivity, any stationary uplift, and for a wide class of dynamic models seems to explain the "universal" character of topographic self-similarity (with $H = 0$) and its robustness relative to uplift rate and horizontally stratified geologic conditions.

THE AFTERSHOCK SERIES OF EVENT 18 FEBRUARY 1996. A COMPLEX BEHAVIOR?

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On February 18, 1996, an earthquake of magnitude M=5.3 occurred at the eastern Pyrenees. Probably, this event is associated to the Agly Massif-North Pyrenees fault system, with recent tectonic activity and important historical seismicity. The continu ous digital recording broadband seismic station CAD, 80 Km apart of epicenter, allows us to perform an analysis of the aftershocks series with magnitudes greater than 1.8. As a first result the aftershock series does not fit Omiri's law. A closer look at the series show that the shape of the cumulative number of aftershocks presents changes of concavity. We define i) a "cascade" ofthose events as the events with negative concavity (defining as positive the concavity corresponding to Omori's law), and ii) the "aftershock" as a cascade of events. Thus defined, the reduced series fit quite well Omori's law with exponent p = 0.7. The events that define the cascade occur at a constant rate, and the velocity of the different cascades decreases with increasin g time, following a power law. The cascade can be interpreted as a discrete rupture of an asperity. By means of numerical experiments, we have seen that complex behavior of the original series of aftershocks can be simulated with a SOC model.

ELECTROMAGNETIC WAVE PROPAGATION IN A RANDOM FAT FRACTAL LAYERED EARTH.

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In the present contribution, we study numerically the electromagnetic wave propagation through one-dimensional random fat fractal layered structure. This model can serve as a model of porous media or of the near surface layers of the earth. Our calculations lead to the conclusion that the behaviour of electromagnetic data measured in the earth's surface depends on the fractal exponent. In order to characterize the behaviour of the impedance we introduce its dimension which turns out to be between two and three. Furthermore, the convergence of the numerical approach is discussed.

NON-LINEAR EFFECTS IN MINERAL GEOTHERMOMETERS AND GEOBAROMETERS BY PHASE EQUILIBRIA.

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The Gibbs-Duhem equations for 5-7 mineral's phases may have non-linear functions in multi-component systems (f.ex.: GR-BT-STAVR-KY-QU). It is possible if many components participate in the synthesis/destruction of several phases. The computation of this systems it was found out, that temperature and pressure are non-linear functions of chemical composition of minerals, it is even possible to observe periodical waves of concentration Mg, Fe, Mn in granats with the increase of temperature. This fact may be of utmost importance as the limiting factor of mineral geothermometers and geobarometers application in the metamorphic petrology.

Chaotic Fluctuations and Bistability - the Effects of Adiabatic Heating on Vigorous Thermal Convection

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D. A. Yuen (Minnesota Supercomputer Institute, Dep. of Geology and Geophysics, Univ. of Minnesota, U.S.A.)

We have studied the behavior of thermal convection in the presence of a strong influence of adiabatic heating. The flow has been investigated in the limit of infinite Prandtl number. Such a system resembles scenarios in which a fluid layer is characterized by a surface temperature T0 being high,as compred to the temperature drop across the layer.The Earth's outer core and the Jovian moon Io are good examples of such a system. With two-dimensional models we have explored the parameter space as spanned by the Rayleigh number Ra and the surface temperature T0. The values of Ra are ranging between 10**7 and 10**15 and of T0 between 0.2 and 5.0. For cases with a high Ra (> 10 **12) and a T0 higher than 1 the flow developed a clearly bistable behavior. The flow oscillates between one stage, characterized by a well ordered cellular flow pattern and another one ,exhibiting a chaotic flow structure. The well-ordered stage is associated with a high heat transport, the minimum heat transport is reached in the chaotic phase. At high Ra the thermal field is dominated by the adiabatic heating ,leading to a thermal profile akin to an internally heated system. The time series of the flow amplitude resembles the features of a globally fractal series. Such systems can potentially lead to a better undertanding of geophysical phenomena with a clear bistable character , such as the geodynamo.

NP1.2/HS18 Scaling, fractals and nonlinearity in hydrology

Convener: Onof, C.
Co-Conveners: Olsson, J.; Over, T.M.; Veneziano, D.

Fractal Ordering of Hydrodynamical Patterns

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This paper deals with fractal ordering of different hydrodynamical laboratorial patterns. Instead of solving the governing partial differential equations for the generally hydrodynamical case, statistical analysis of the laboratorial pictures can be an alternative solution of determining different hydrodynamical parameters. In possession of laboratorial pictures with fractal characteristics different statistical function can be elaborated i.e. calculating the block-dimension of a part of the picture. We will show our results is the fractal ordering method, based on the block-counting dimension. Originally a picture is stored by quadtree structure and coded by appropriate ordering system. This method can be based on fractal geometry: the space-filling curves. The problem of using the space filling curves in our case is that for the different pictures the encoding method can not be the same. That is way we try to use in our analyzing system the fractal encoding method with the same block-counting dimension as determined by the laboratorial experiment. A problem is occured when one uses the inverse algorithm (from a block-counting dimension to a fractal shape) because this is an one to infinity connection. This raises an issue that the convergence of the encoding method may be disturbed. In this paper we show and proof a physical based algorithm to choosing a correct fractal shape for ordering hydrodynamical fractal images.

GEOSTATISTICAL CHARACTERIZATION OF RANDOM CASCADE FIELDS APPLIED TO THE SAMPLING OF RAINFIELDS

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The first point considered in this study is a geostatistical characterization of cascade random fields. It is pointed out experimentally on generated cascade fields and theoretically that the variogram of cascade fields presents a nugget effect which is independant of the cascade generator model. This nugget effect is function of the branching number and the parameters of the generator model. In the case of a b-model, the nugget effect can be used as a new method to estimate b. The b-estimate given by this method is compared to that produced by other approaches. The second point considered is the sampling problem for the estimation of random cascade field parameters. Given a generator model, cascade fields are generated for different values of parameters by considering different levels of sampling for the calculation of the high frequency component of the cascade field. From the simulated fields the cascade parameters are estimated. The deviation between the cascade fields sampled at various frequencies and the original field is analysed and the nature of this deviation is used to estimate approximately the cascade parameters in for low-frequency sampled fields such as those produced by raingage networks.

PREDICTING THE DISTRIBUTION AND GEOMETRY OF FRACTURE APERTURES IN THE CHALK AQUIFER.

John Bloomfield (Hydrogeology Group, British Geological Survey)
John Barker (University College, London)

The high transmissivity of the Chalk is attributed to flow through a preferentially enlarged component of the fracture network, and solution enlarged channels may play an important role in the rapid transport of contaminants. However, little is known of the distribution and geometry of solution enlarged fracture apertures. The present study attempts to constrain the problem by using a phenomenological model to investigate the affects of initial aperture distributions and aperture growth laws on the evolution of aperture geometries. Head and velocity distributions are calculated in an idealized 2-d fracture array and the velocities are substituted into an aperture growth rate law, of the form da/dt = fn (q^n), to calculate new fracture apertures. The procedure is then repeated using the new apertures. Low flow rate exponents and small initial aperture variations lead to relatively homogeneous aperture arrays with strong 'parallel plate' geometries, higher flow rate exponents and larger initial variations lead to heterogeneous aperture distributions with complex geometries and in many cases to single, tortuous, channels. Statistical and spatial correlation analyses and multifractal methods can be used to characterise the aperture distributions.

MULTIFRACTAL STUDY OF THE THREE DIMENSIONAL SPATIAL DISTRIBUTIONS OF RAIN AND SNOW IN 10 M^3

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Empirical observation of rain reveals multiscaling behaviour over considerable ranges of scale. This is in contrast to the standard homogeneity assumptions used for modeling drop growth or aggregation or the interpretation of radar reflectivities from rain or snow. High space/time resolution radar rain data reveal multiscaling behaviour down to the resolution scale of a radar pulse volume and theory shows how this can be interpreted in a multifractal framework. If this behaviour continues at sub-pulse volume scales, it will lead to large systematic biases in radar estimates of rain. However, radar resolution scales prohibit the direct verification of this sub-resolution behaviour. In order to directly test the hypothesis that the drop field exhibits multiscaling behaviour at small scales, stereo photography is used to detect rain drops or snow flakes in a volume ≈10 m^3. Hydrometeors are lighted by two powerful xenon flashes (50 µs, 2000J). Three motorized Hasselblad cameras help provide accurate estimates of their three dimensional position as well as their size. The overall range of scales is close to 10^4 in all directions. Multifractal analyses relating to the field of liquid water content (for rain drops) and equivalent liquid water content (for snowflakes and ice crystals) are performed and the implications for radar measurements of rain are discussed.

FRACTAL INTERPOLATION OF PRECIPITATION FIELDS

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Recent research has indicated that rainfall may exhibit multiscaling characteristics. A realization of multiscaling process can be viewed as a real-valued self-similar or self-affin field. That is the reason why a new type of "surface-fitting" technique, the fractal interpolation method can be useful to approximate precipitation fields based on raingauge measurements. The fractal interpolation method fits fractal function to the experimental data in a new sense. The graph of the fractal interpolation function has to be close to the data in the Hausdorff metric. Moreover, we require the fractal dimension of the graph of the interpolation function to agree with that of the data over certain range of scales. Preliminary information (like the fractal dimension of the graph) can be calculated by multifractal analysis of rainfall fields measured by weather radar. The paper presents the results of a multifractal analysis for the radar rainfall data measured in Hungary, and some preliminary results for the fractal interpolation of precipitation fields. The impact of data on the result of fractal interpolation is also investigated.

MULTISCALING PARAMETER ESTIMATION FROM RAIN MEASUREMENTS

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Abstract

The uncertainty of multiscaling parameter estimates due to finite sample size is addressed as well as the effects of noise and instrument artifacts on the quality of scaling and accuracy of parameter estimation. Using self-similar cascade simulations we investigate the degree of uncertainty in parameters such as the Fourier spectrum scaling exponent, β, and the codimension of the mean, C_1. Uncertainty in these parameters is discussed in relation to the amount of data available and the length of the scaling range. Simulations of noise and specific instrument artifacts are carried out to investigate the effects of noise and artifacts on scaling and parameter estimates. Noise and other artifacts may introduce scaling breaks and may bias parameter estimates. Specific examples of noise and artifacts include the tipping bucket effect in rain gauges and weather radar noise and artifacts. The tipping bucket effect has pronounced effects at low rainfall rates and thus corrupts analyses of moment scaling especially for low-order moments (q<1).

.TIFRACTAL ANALYSIS AND FORECAST OF SPACE-TIME NFALL FIELDS

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he use of space-time multifractals in order to describe the dynamics of rainfall een proposed by Marsan et al. (Journal of Geophysical Research, 1996), and spond to a mere generalization of anisotropic multifractals to causal multifractal sses. This proposal is tested on rainfall estimates from radar reflectivity data; al problems arise, implying new techniques of multifractal analysis: Eulerian iption of an Lagrangian mutlifractal process, estimation of the scaling tropy between space and time...
Moreover, we exploite the multiscaling properties so to predict the future state of cess known up to a given time: an original method, based only on these iscaling properties, is thus proposed and tested.

SPATIAL RAINFALL DISAGGREGATION FOR LARGE SCALE HYDROLOGICAL MODELLING

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A disaggregation model which preserves important spatial features of the rainfall fields is required to enable hydrologists to work at large grid-scales with corresponding rainfall information. The proposed method considers separately the reproduction of the wet areas and the simulation of rainfall intensities. For the first task, a Nearest Neighbour Markov scheme based upon a Bayesian technique used in Image Processing is implemented in such a way that the disaggregation uses the precipitation field at the previous time-step as prior information. Essentially, the large scale field is used as an initial value in an iterative procedure which uses the posterior probabilities of the field. The second task is dealt with by seeking to reproduce both the morphological characteristics of the rainfall field and the distribution of rainfall intensity at a single point. The gamma distribution with a parameter dependent upon the large-scale rainfall is used and the sampled rainfall intensities are assigned to grid-squares according to the distance to the edge of the field.
The scheme is implemented for two different sets of radar data: Arkansas in the USA and Wardon Hill in the UK and the reproduction of some of the spatio-temporal features of precipitation is examined.

THE FILTRATION PROBLEMS SOLUTION USING FRACTIONAL DERIVATIVE TECHNIQUES.

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It is known that the classical filtration equations application are not always suitable for the description non-steady-state hydrodynamic flows in working strata. The consideration of liquids and gases filtration through saturated porous and crack-porous rocks as of casual process in fractal environments results in an idea to use the fractional calculus procedures for the solving the hydrodynamic problems. The author received the filtration equation in fractional derivatives and its solutions for problems of pressure restorations, debit falling, pressure periodic changes in oil wells. The interconnection between fractal dimension and fractional degree in the differential equations is discussed. The comparison of received solutions with experimental data and traditional filtration equations allow to make a conclusion that the fractional differential equations may be applied to solve the filtration problems and for explanation of some nonlinear effects in hydrology.

UNDERSTANDING RAINFALL DETERMINISTICALLY?

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Usage of a deterministic fractal-multifractal, FM, approach to model high resolu tion rainfall time series is reviewed. It is shown that the FM methodology preserves the intrinsic shape and variabilit y present in real rainfall records, allowing to interpret them as projections of f fractal functions. Results for an 8-hr storm gathered in Boston every 15 seconds on October 25, 198 0 and two 12-hr events measured in Iowa City every 5 seconds on November 1 and N ovember 30, 1990 are given. It is illustrated that the FM approach provides very faithful descriptions of bo th major trends and small (noisy) fluctuations for these storms, resulting in pr eservation of not only classical statistical characteristics of the records, but also multifrac tal, and chaotic properties (when) present in them.

These results suggest that a stochastic framework for rainfall may be bypassed i n favor of a deterministic representation based on the concept of projection. Pertinent sensitivity analysis results, extensions and forecasting implications are presented.

PREDICTING GROUNDWATER POLLUTION VIA A DETERMINISTIC MODEL OF PLUME GEOME TRY

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A parsimonious geometric procedure for the description of two-dimensional contam inant plumes, as projections off fractal functions whose graphs lie in three-dim ensional space, is reviewed. It is shown that successful usage of the ideas, to represent successive spatial chloride concentrations as gathered during the Borden site experiment in 1982, y ields a new approach to plume dynamics based on the evolution of surrogate geome tric parameters. It is illustrated that those geometric parameters, some of which are related to dispersion coefficients, exhibit simple trends (in time) which allow predicting the movement of the plume.

Plausible predictions, computed by finding alternative fits to the observed tren ds, are given. It is shown that such predictions: (a) preserve the non-Gaussian and elongated n ature of the chloride patterns, and (b) have covariance tensors which closely ag ree with those implied by stochastic (Gaussian) transport theories (Dagan, 1984) . A generalization of the geometric procedure, to model three-dimensional groundwa ter pollution plumes, is provided.

MULTIFRACTAL ANALYSIS AND DOWNSCALING IN HYDROLOGICAL TIME SERIES

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The multifractal characteristics of two different scaling regimes found in the spectrum of the Belgium rain rates times series are investigated. We first estimate the multifractal exponents associated to the high (between 10 min. and 15 days) and the low-frequency regimes (larger than 15 days). This last regime which possesses a nearly flat spectrum can be viewed as a "multifractal noise" acting at large scales. Under this assumption, we analyze the possibility to generate a multifractal cascade conditionally dependent on the large scale noise. We furthermore validate this approach through a carefull comparison with the statistical properties of the original data.

SCALING LAWS OF FLUVIAL TOPOGRAPHY FROM SELF-SIMILARITY

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In a companion paper (Veneziano *et al.*, EGS 1997), we have shown that, in self-similar (ss) fluvial topography, elevation $h(x,y,t)$ should satisfy $\{h(x_1,y_1,t) - h(x_2,y_2,t)\}|_A =^d r^{H}\{h(rx_1,ry_1,t) - h(rx_2,ry_2,t)\}|_{r^2A}$ where (x,y) are coordinates relative to the main stream source and $|_A$ refers to a sub-basin of area A with outlet on the main stream. We also found that, under rather general conditions, physically-based dynamic models produce ss topographies with $H = 0$. Here we use self-similarity to derive and extend geomorphological scaling laws of hydrologic interest. We find that several existing laws should be modified, as they have been derived using inappropriate measuring techniques. For example, when flow distance is measured using a ruler whose length varies as $A^{0.5}$, then Hack's Law exponent α and the exponent γ of the contributing area distribution should both be 0.5. We argue that this is the correct way to measure flow distance in ss topographies. For the case when the ruler has constant length, which is the usual practice, we obtain $\alpha \geq 0.5$ and $\gamma = 1 - \alpha$, which are consistent with usually reported values. Based on self-similarity, we reformulate Tokunaga's cyclicity concept for drainage networks, in a way that includes both geometric and topologic features. Our definition relies on drainage area rather than stream orders which are undefined in ss topography. We also show that many natural river profiles are consistent with h being ss with $H = 0$, as predicted by theory. In the past, different conclusions were reached on the self-similarity of such profiles, based on ss conditions other than the one above. Finally, we show in which sense river courses are ss.

NP1.4/ST8 Nonlinear dynamics in the heliosphere: shocks, solitons and fractals

Convener: Macek, W.M.
Co-Convener: Marsch, E.

STRONG ALFVEN WAVE EVOLUTION ON SOLAR WIND LOCAL DENSITY INHOMOGENEITY

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The interaction of strong nonlinear Alfven wave with intensive density inhomogeneities in the interplanetary plasma is considered in one-dimensional approach. The Alfven wave form dynamics evolution is investigated in dependence on plasma parameters and inhomogeneity characteristics. Computer simulations show how shock Alfven wave undergoes reversible form changing in high density region - shock wave oscillations decrease here and then restore in more rarefy media. Simulations show also how in result of strong Alfven wave with inhomogeneity interaction dispersed Alfven wave and magnetohydrodynamic disturbances of various types arise. The role of plasma temperature for these processes is investigated, it determines sound speed and changes the interaction between shock Alfven wave and slow magnetic sound waves.

ALFVEN WAVE PARAMETRIC SCATTERING BY SOLAR WIND TURBULENCE

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Parametric interaction processes of Alfven (A) waves with different kinds of waves on experimental solar wind wave turbulence (T) background were studied within the kinetic equation for plazmons' distribution function in inhomogeneous medium. Quantities of the following A wave effective attenuation were calculated. Interaction process of A wave with fast magnetosound (FMS) wave when A wave merges with FMST background is important for large scale T. Parametric interaction of A wave with slow (SMS) and A waves in presence of FMST and SMST, accordingly, is significant for small scale T. Taking into account the parameter distribution of interplanetary medium along wave transport trajectory it was shown, energetic changes occur with small scale A wave package in upper corona and with large scale A wave package - far from the Sun. During observations these findings make possible the definition of near solar space spherical layers responsible for A waves of specific scales.

GENERALIZED EXTENDED SELF–SIMILARITY IN THE SOLAR WIND TURBULENCE

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Extended Self–Similarity (ESS) has been found to exists in ordinary fully developed turbulence when we plot the q–th order velocity structure function vs. the third-order structure function $S_r^{(q)} \sim [S_r^{(3)}]^{\alpha_q}$. Quite surprisingly the range of scales r where this is verified extends well beyond the usual inertial range, covering the whole range of scales. This behavior exists also in the Solar Wind turbulence and allows us to recover a set of scaling exponents α_q which can be compared with the usual model for intermittency.
However we found that, when we investigate the scaling laws for the magnetic structure functions, in some cases the ESS fails and a departure from the scaling is observed. In these cases we found that a generalized form of ESS always exists. On this basis we can introduce a conjecture for the existence of ESS in both the normal and generalized form. This conjecture is based on the presence of localized velocity and magnetic shears which, acting as local sources of turbulence, could introduce a dependence on the scale r of the scaling parameters related to the multifractal model.

ON ALFVÉN WAVE FILAMENTATION

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A mechanism for small-scale generation in magnetically dominated homogeneous space plasmas is proposed, resulting from transverse collapse (filamentation) of weakly nonlinear Alfvén waves. Special attention is devoted to the zero dispersion limit governed by a generalized vector nonlinear Schrödinger equation, for which the focusing is anisotropic, leading to a splitting of the collapsing centers and the formation of complex small-scales structures.
In the non-stationary regime, it is shown that if the emission duration of the wave-packet is short enough, the collapse can be arrested by magnetosonic waves which intensify in the form of sharp acoustic fronts.
Estimate of the energy burned out in the collapses, shows that Alfvén wave filamentation provides an efficient heating mechanism in the solar corona and significantly contributes to the acceleration of the solar wind.

MAGNETIC HOLES: MIRROR MODE STRUCTURES VERSUS SLOW MA MODE-TYPE SOLITONS

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'Magnetic holes' (MH's) - depressions in the magnetic field magnitude associated with enhancements in kinetic pressure - have been observed in the solar wind, the magnetosheaths of terrestrial planets and in the environments of comets. They are commonly believed to result from the mirror instability which can develop in high beta plasmas with a temperature anisotropy, $T_\perp/T_\parallel > 1$. We introduce an alternative mechanism into the discussion over the physical nature of MH's that is not related to the mirror mode. We suggest an explanation in terms of slow mode-type MHD solitons which propagate with small velocities at large angles to the magnetic field. These structures can evolve as stable flow features in the sense of inverse scattering theory, from certain initial conditions in the solar wind plasma, without the need for a temperature anisotropy. This approach allows direct access to the amplitude and the thickness of MH's in a fair agreement with observations.

SIGN–SINGULAR MEASURES IN THE SOLAR WIND TURBULENCE

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By using *in situ* satellite observations of the magnetic fields, we investigate the apparent random behavior of the magnetic helicity H_m. Our data analysis is based on the introduction of a signed measure related to H_m. This measure can show a singularity related to extreme oscillations in sign, the scaling behavior of cancellations between positive and negative contributions being characterized by a scaling exponent κ. We found that helicity is sign–singular, a property which underlies to the dominance of a single sign of polarization for fluctuations at small scales. We also found a statistical correlation between κ and the bulk Solar Wind speed. We stress that, even if the usual models based on random phases (introduced to describe magnetic fluctuations) are able to reproduce (in a statistical sense) the gross features of H_m, they cannot reproduce the sign–singularity. A different model for the magnetic fluctuations is then outlined.

SOLAR ACTIVITY AND SOC

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Large dynamical systems tend to evolve (self-organize) into a critical state, when a minor perturbation may lead to avalanche-like instability. In such systems relatively quiet periods are followed by periods of increased activity triggered by an instability in a stochastic way (punctuated equilibrium behaviour). Self-Organized Criticality (SOC) has been proposed as an unifying concept describing the dynamics of such systems characterized by response functions obeying power-laws and self-afine geometry.
In this paper we analyse time series of solar activity represented by Wolf sunspot number and sunspot area using the concepts of SOC. We transform the original time series on the basis of accumulated activity curves and punctuated equilibrium criteria. Then we show that the transformed time series exhibit clearly all the periodicities of solar activity with no impressions of time or frequency domain filtering techniques.

NONLINEAR DYNAMICS OF PRECURSOR WAVES OBSERVED UPSTREAM THE EARTH'S BOW SHOCK

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Many experiments have reported the existence of discrete and highly polarized wave packets at the leading edge of collisionless shocks. It has been conjectured that these wavetrains do not result from a plasma instability but rather constitute an inherent part of the shock dynamics itself. Yet, attempts to experimentally identify their leading generation mechanism haven't been successful so far.
Motivated by this problem, we have carried out a detailed analysis of magnetic field data gathered by the AMPTE spacecraft upstream the Earth's quasiparallel bow shock. By extracting the wavefield dispersion relation and the spectral energy transfer rate that characterizes nonlinear wave interactions, new insight has been gained into the nonlinear dynamics of the wavefield. The results show that the precursor waves issue from a competition between dispersion and nonlinearity. A simple model for the creation of these wavetrains from propagating magnetosonic waves of the Riemann type reveals major dynamical characteristics of the underlying physics.

DYNAMICS OF THE MIDDLE- AND SHORTSCALE SOLAR WIND FLUCTUATIONS NEAR THE BOW SHOCK.

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Fluctuations of the solar wind ion flux, electric and magnetic fields are studied on the basis of in situ measurements with time resolution from 16 s up to 0.02 s. Wavelet analysis are used by means to investigate the dynamic features of the processes in the different time/space scales. Amplitudes, time scales and dynamics of the parameter fluctuations are compared for three regions: undisturbed solar wind, foreshock ahead of quasiparallel bow shocks and foot/front of quasiperpendicular bow shocks. Middlescale fluctuations of ion flux and magnetic field in the foreshock show a good correlation at the scale from hundreds to tens of second. Comparing of the similar measurements by the two s/c (main sattelite and its subbsatellite) at the distanse about 1000 km alow us to estimate the moving and size of thin solar wind structures. The high frequency (about 1 Hz) ion flux fluctuations significantly increase at the shock front and (in difference to the electric field ones) maintain this high level during many tens of minutes at the downstrem flow.

NON-LINEAR PARTICLE ACCELERATION IN OBLIQUE SHOCKS

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We have developed a Monte Carlo technique for self-consistently calculating the hydrodynamic structure of oblique, steady-state shocks, together with the first-order Fermi acceleration process and associated non-thermal particle distributions. Our method overcomes the injection problem faced by analytic descriptions of shock acceleration, and the lack of adequate dynamic range and artificial suppression of cross-field diffusion faced by plasma simulations. We present solutions for plasma quantities and particle distributions upstream and downstream of shocks, illustrating the strong differences observed between non-linear and test-particle cases.

NONLINEAR LOW-FREQUENCY WAVES IN SPACE PLASMAS

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Collsisionless shock are generically related to low-frequency nonlinear waves (magnetosonic, Alfven waves, and whistlers). There is a plenty of low-frequency turbulence and probably coherent large-amplitude waves within and in the vicinity of the shock front. Moreover, classical theoretical scenario of the quasiperpendicular fast shock formation describes it as a transformation of a fast magnetosonic soliton into a shock-like structure, when some dissipative mechanisms, like for example, ion reflection, are included. Therefore, knowledge of the nonlinear low-frequency wave features would mean important implications for the shock theory. We review the features of these waves, including dependence on the plasma β and angle of propagation, and the implications for the shock structure. We consider in detail the behavior of the quasistationary one-dimensional nonlinear waves within the framework of hydrodynamical description of the hot plasma. Particular attention is devoted to the propagation of fast magnetosonic waves and existence of soliton-like structures.

STRUCTURE FUNCTION ANALYSIS OF SOLAR WIND TURBULENCE

T. S. Horbury (The Blackett Laboratory, Imperial College, London England)

Recent analyses of Ulysses magnetic field data will be presented. A structure function analysis of small scale fluctuations reveals approximately inertial range turbulence. This turbulence is intermittent, in common with terrestrial turbulence. Comparison with several popular models of intermittent turbulence shows that the p model of Meneveau and Sreenivasan provides the best description of the fluctuations. The reliability of structure function estimates will be discussed in some detail and a simple criterion for the rejection of unreliable results will be presented. In addition, a novel application of wavelet analysis to the study of MHD turbulence, which can provide intermittency information about anisotropic fluctuations, will be discussed.

RELAXATION OF THE SHOCK WAVE-REFLECTED ION BEAM, AND GENERATION OF HOT ELECTRONS

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Using results obtained by collisionless shock wave (CSW) experiments on a laboratory device it presents a systematization of relaxation regimes of the ion beam both in the region of main jump of the magnetic field ("ramp") and in the zone of impinging plasma flow. Ahead of the CSW front a reflecting jump of the electrostatic potential was recorded, which was formed by the ion beam reflected by potential hump in the ramp region. An electron acceleration effect in the ion-ion interaction region ahead of the CSW front to energies of about 100 initial temperatures was detected. Hot electrons anomalously rapid propagate from this region across the magnetic field in the form of a localized disturbance. In the neighbourhood of the ion reflection zone in the ramp region, a nonadiabatic heating of electrons to energies about the value of the electrostatic potential within the CSW was detected. Analysing the experimental results authors suppose that the transverse magnetosonic shock wave in a collisionless plasma has the following common structural characteristic: hot electron region - turbulent region, occupied by the reflected ion flux, - diffuson magnetic footing - jumps of plasma parameters and the magnetic field - relaxation region behind the CSW front. Applications of obtained experimental results to solar-terrestrial physics is discussed.

NON-LINEAR ANALYSIS OF TIME-SERIES OF THE MAGNETIC FIELD INTENSITY

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Z. Voros - Geophysical Institute of Slovak Academy of Sciences, Slovakia
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The behaviour of an open system, like the Earth's magnetosphere. is influenced by the inflow of outer energies. In the case of the magnetosphere, the dissipation of this energy is supposed to take place upon the so-called inhomogeneous cascade model of turbulent processes. The aim of this study is to investigate the statistical roperties of the structures of the evolved turbulence field. The analysed data sets are the one-year long minute-mean records of the magnetic field intensity that were collected by different observatories of the Earth. The empirical probability distribution functions, and the power spectra of the time-series will be presented. The inhomogeneous distribution of the turbulent eddies is examined by the aid of the structure functions. We investigate the scaling of these functions in order to prove the fractal or multifractal character of the statistical distribution of the evolved turbulence field.

STOCHASTIZATION OF PHASES IN FOUR-WAVE INTERACTION

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We consider the one-dimensionnal interaction of three Langmuir waves with a ion- sound wave. Energy input or dissipation is made through linear growth rates or d amping, considered as parameters. We study this system giving a particular atten tion to the pha Numerical simulations of the Zakharov equations showed that the "cascade" predic ted by the weak turbulence theory is often truncated after three or four peaks [e.g. Hanssen et al., J. Geophys. Res., 97, A8,1992].
The three-wave interaction with a mistmatch in resonance conditions may lead to stochastization of phases, but is unable to saturate the instability at exact re sonance [e.g. Wersinger et al., Phys Fluids 23(6), 1980].
The four-wave model c an describe a c

NUMERICAL SIMULATION OF THE STRONG TURBULENCE ORIGINATED BY AN ELECTRON FLUX IN SPACE PLASMA

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In many cases charged particle fluxes interact strongly with space plasma causing plasma turbulence. Such interactions are noticed in auroral ionosphere, in shock region, during active plasma experiments, etc. We present the results of 1D computer simulation of nonlinear dynamics of electron beam injected into the half-space with electron-ion plasma. The following consequence of events has been observed: Langmuir waves build up due to the two-stream instability, effect of plasma waves accumulation, trapping of the bulk of ambient electrons by generated wave, collisionless plasma heating due to the mixing of particles in phase space, appearance of the ion density irregularities and Langmuir solitons (modulation instability), and the trigger character of beam-plasma interaction. Results of computer experiment we compare with existing theories as well as observational data.

FRACTAL ANALYSIS OF THE SOLAR WIND

Wiesław M. Macek (Space Research Centre, Polish Academy of Sciences, Bartycka 18 A, 00-716 Warszawa, Poland)

There is mounting evidence from recent data analysis that the turbulence in the solar wind is not fully described by Fourier analysis. Further, the probability distributions for the slow solar wind are clearly non-Gaussian at small scales. Random data usually give rise to a Gaussian probability distribution function of measured parameters. For chaotic data the distribution is likely to be a fractal, even though the normal distribution is not excluded. The results of research on scaling and fractal properties of the solar wind fluctuations will be considered. In particular, we analyse time series of plasma parameters of low-speed streams measured by the Helios spacecraft in the inner heliosphere, which is a region of space dominated by the solar wind flow. The application of time-series fractal analysis and structure functions, which are new nonlinear methods for data analysis, is especially relevant for studying the question of whether the irregular behaviour of the solar wind flow results from intrinsic nonlinear chaotic dynamics or from external forces.

NONLINEAR DYNAMICS OF COHERENT AND SOLITARY ELECTROSTATIC WAVE STRUCTURES WITH APPLICATIONS TO SOLAR WIND OBSERVATIONS

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Nonlinear solitary and coherent electrostatic wave structures were discovered recently by the Wind spacecraft near the Lagrangian point (see the abstract by *Salem et al.*). In order to examine possible nonlinear mechanisms which can lead to the appearence of such structures in the solar wind plasma, with hot and cold electron populations and a proton temperature comparable with the cold electron temperature, an analytical analysis and kinetic Vlasov simulations were carried out. The results indicate that under certain conditions the development in the nonlinear behaviour of the finite amplitude electron acoustic oscillations can reproduce wave forms observed during the experiment on board of the Wind spacecraft. Necessary conditions for solar wind plasma parameters to allow such nonlinear structures to develop will be presented as well.

SOLITONS IN BI-ION PLASMAS

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In space plasmas heavy minor ions frequently occur in the solar wind, in the vicinity of comets, and in front of travelling interplanetary shocks and planetary bow shocks. The appearance of minor ions is associated with low frequency plasma waves as demonstrated by extraterrestrial in-situ measurements. The plasma waves are treated by means of multi-fluid equations. A perturbation theory is developed for a left-hand circularly polarized, low frequency plasma wave. Taking the first nonlinear terms into account, the multi-fluid equations are reduced to a nonlinear Schrödinger type equation. The derived solitons are only appearing in a magnetized bi-ion plasma. The properties of these solitons are discussed for plasma parameters usually found in the solar wind. An enhanced abundance of helium ions is observed within these solitons.

STRUCTURAL INSTABILITY OF DISCONTINUOUS MAGNETOHYDRODYNAMIC FLOWS

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In the recent years the interest to structural instability of discontinuous flows resumed due to the new satellite observations of the heliosphere. We consider this phenomenon from the view point of the principle of evolutionarity in the framework of magnetohydrodynamics. For a non-evolutionary discontinuity the problem of time evolution of its small perturbation does not have a unique solution, therefore it cannot exist as a stationary configuration. At the present time the nonlinear evolution of such discontinuities is a matter of debate. We show that the governing factor of their behavior is that a non-evolutionary configuration can be represented as a set of more than one discontinuity. It is thus structurally unstable and must disintegrate into evolutionary discontinuities or transform to some more general non-steady flow. We generalize the principle of evolutionarity to inhomogeneous and dissipative flows. As a result we obtain new criteria of structural instability for quasi-one-dimensional configurations, such as a reconnecting current sheet, as well as for the discontinuities in the profile of inviscid shock waves. This allows us to explain the unclear features of discontinuous magnetohydrodynamic flows observed in numerical experiments.

POLYSPECTRAL ANALYSIS OF SLAMS EVENTS OBSERVED AT THE EARTH'S QUASI PARALLEL BOW SHOCK

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Statistics of order 3 (bicoherence) and 4 (tricoherence) are used to analyse SLAMS (Short Large Amplitude Magnetic Structure) events, observed by the AMPTE-UKS spacecraft at the Earth's quasi-parallel bow shock. Two different treatments are performed, one on the full time series, the other on time intervals on which SLAMS have been identified. This identification is made both as in Schwartz et al. (J.Geophys. Res., 97, 4209, 1992) and from estimated values of the non-mormalized skewness. Strong peaks in the tricoherence function point out the presence of four wave non-linear interactions. A residual is seen on the bicoherence. Comparison of non-linear interaction with directly calculated growth rate and damping from bi-satellite data is carried out. Interpretation in terms of an inverse parametric decay from the SLAMS frequency towards the ion gyrofrequency is proposed.

NONLINEAR STAGE OF ALFVÉN WAVE PHASE MIXING

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The nonlinear coupling of Alfvén and fast magnetoacoustic waves in a magnetised compressible plasma with transversal inhomogeneity of plasma density is considered analytically and numerically. The inhomogeneity leads to the generation of transversal gradients of magnetic pressure due to phase mixing of the Alfvén waves. These gradients excite fast magnetoacoustic waves, a part of which propagates across the magnetic field and moves energy from the regions with the sharpest gradients in the density. Due to refraction, the fast waves shift to regions with low Alfvén speed. Oblique propagating fast magnetoacoustic waves may be subject to effective dissipation leading to plasma heating which is spread around the region of the density inhomogeneity. Moreover, the fast waves contain perturbations of plasma density and can be a source of particle acceleration. The efficiency of the nonlinear interaction of the Alfvén and fast waves depends upon the strength of the inhomogeneity resulting in secular temporal and/or spatial growth far from the source of Alfvén waves.
The proposed mechanism offers an explanation for the observed appearance of magnetoacoustic fluctuations in the solar wind far from the Sun, together with a decay in Alfvénicity. The mechanism is also important for solar coronal heating.

EXTRACTING NONLINEAR DYNAMICS FROM THE SOLAR WIND

Lidia Obojska and Wieslaw M. Macek (Space Research Centre, Polish Academy of Sciences, Bartycka 18 A, 00-716 Warszawa, Poland)

We analyze a time series of velocities of low-speed streams measured by the Helios spacecraft in the inner heliosphere. We apply the method of singular value decomposition to represent the data in terms of a complete set of orthogonal functions. By neglecting some eigenvalues of the trajectory matrix we remove a substantial amount of noise. We show that, a simple nonlinear function of these basic functions is sufficient to reproduce the nonlinear dynamics of the system. Some geometric invariants of the dynamical system, as fractal dimension and entropy, are also calculated. These results provide evidence that the inner heliosphere is likely to be a nonlinear chaotic system.

SOLITARY AND COHERENT ELECTROSTATIC WAVES IN THE SOLAR WIND

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The Time Domain Sampler experiment, on board the WIND spacecraft, measures electrostatic waveforms with a very good time resolution (up to 10 μs). We study the waves detected in the solar wind near the Lagrange point : the waveforms appear as solitary spikes (lasting less than 1 ms) or coherent wave packets (1 to 6 kHz). Some waves are also observed at the electron plasma frequency (around 20 to 30 kHz). The occurrence of the electrostatic waves is studied as a function of the solar wind velocity, of the temperature ratio T_p/T_e, and of the shape of the electron and proton distribution functions. We discuss the results of simulations, using a 2D Vlasov code, of the electron acoustic instability.

TURBULENCE DOWNSTREAM OF QUASI-PARALLEL COLLISIONLESS SHOCKS: SIMULATIONS

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We will discuss one-dimensional hybrid simulations (massless electrons, macro ions) of almost parallel collisionless shocks over a wide range of Mach numbers. One of the key questions is whether downstream convected upstream waves or waves locally generated at the interface of the incoming solar wind and the partially thermalized plasma are the main source of the downstream turbulence. In the medium, supercritical Mach number regime the small-wavelength interface waves are damped in a transition region and contribute to downstream dissipation. These waves are right-hand polarized and propagate in the downstream rest frame toward the shock. In an Alfvén Mach number regime around $M_A \sim 8$ we find behind the shock ramp right-hand polarized waves with both helicities. This is interpreted in terms of both the ion/ion resonant and the ion/ion right-hand nonresonant instability occuring in the shock transition region. In this Mach number regime the shock produced waves have larger wavelengths and are less strongly damped. It is suggested that they are subject to a parametric decay instability, resulting in an inverse cascade of short-wavelength waves to longer ones further downstream. In the very high Mach number regime damping as well as decay of the shock produced waves is slow compared to the transit time from the shock to the magnetopause. The shock generated waves are then expected to be the dominant source of the downstream turbulence.

IS THE SUNSPOT CYCLE AN INTEGRAL CHAOTIC ATTRACTOR OF A SYSTEM UNDER GLOBAL CONSTRAINTS

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A non-linear dissipative reaction-diffusion system with characteristic internal cumulative feedbacks and terms of global coupling (i.e. a partial integro-differential equation system) has been investigated on the basis of a 3d-model. Such systems possess particle solutions - sometimes called autosolitons. Enhancing a (control)parameter of the system driving term, the particle creates nearly a limit cycle of the integral of a definite system variable after a Hopf-bifurcation. There arise a spinning internal dynamics. The frequency of the limit cycle is twice as much as the spin frequency. Further increase of the control parameter leads to a second bifurcation creating an integral chaotic attractor. The chaotic character of the attractor has been proved. The new route into chaos is marked by a modulation of the amplitude of the limit cycle by an incommensurable frequency with increasing amplitude. This amplitude becomes unstable and rises exponentially after the bifurcation.
One of the most surprising outcomes of the chaos research is the universal validity of certain results. Although the system does not model solar processes, the integral chaotic attractor shows striking characteristics of the time behaviour of the sunspot number - an integral quantity, too. The typical characteristics of the sunspot cycles will be compared with the model calculations. Assuming the sunspot cycles obey such a chaotic behaviour, some important conclusions can be derived: There are no regular periods but only two quasi regular periods of a statistical mean duration. A long-term prediction of the solar activity is impossible. A depletion of the solar activity, such as the Maunder-minimum, occurs in irregular intervals. There could have happened two catastrophic bifurcations in the history of the sun.

KINETIC DESCRIPTION OF DUSTY PLASMA SOLITONS

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Dust is a common component of many space plasmas and waves in dusty plasmas have recently been considered when the dust grains are charged. Dusty plasma physics is of great importance with a number of application. Recently, attention has been focused on planetary rings in which heavy micron size dust grains are charged to high degree. In particular, in the F-ring of Saturn there is an extreme anomalous situation where the number density of free electrons is much smaller than the number density of ions. This could happen because the charged dust grain collect electrons from the background medium and the number density of free electrons is anomalously small. It is found that dusty plasmas of Space satisfy assumptions leading to collisionless Vlasov plasmas. Vlasov-Poisson/Ampere equations for multi-component plasmas are considered. Assuming suitable equilibrium distributions for cold and hot charged particle/grain components, due to negligence of wave-particle interactions and assuming traveling wave far field solutions, fully nonlinear ODE is gained for SAGDEEV potential. Examples of negative solitary potentials associated with fully nonlinear dust-acoustic waves are computed.

ON SYNERGISM OF ALFVÉN FIELD LINE RESONANCES

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Research on the temporal and spatial structure of wave processes in the magnetosphere has been carried out for a long time. Recently, the fundamental role of Alfvèn field line resonances in the formation of Pc 3 - 5 pulsation fields at high and middle lattitudes has been recognized. It is believed that the frequencies of some of these pulsations are controlled by the solar wind while the frequencies of others are controlled be resonances (eigenmodes) of individual earth field lines. Recent work has shown that cross phase measurements may be used to identify eigenmodes properly.
The main objective of this paper is to provide experimental evidence of nonlinear character of the evolution of geomagnetic eigenmodes and their interaction with the background plasma under varying field conditions. In order to distinguish between deterministic versus stochastic eigenmode processes several nonlinear techniques such as dimension and Lyapunov exponent estimation , nonlinear prediction and multifractal techniques will be considered in the paper.

The influence of the cosmic rays and LISM neutrals on the solar wind termination shock

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The model of the nonpolytropic solar wind in the presence of galactic (GCR) and anomalous component (ACR) cosmic rays is presented. The interaction of the wind ions with the LISM neutrals is taken into account self-consistently by introducing the appropriate source terms in the flow equations. A spectrum of the possible configuratios of the outer heliosphere arises as a result of numerical integration of the model differential equations. The dependence of the shock radius on the initial (at 1 AU) speed and density of solar wind, on the efficiency of ACR production and on the assumed strength of the interction with neutrals is discussed.

Stability of the dust-acoustic solitons

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The stability of the nonlinear wave and solitons solutions is examined in a four component plasma consisting of electrons, two distinct positive ion species and negatively charged dust grains. The stability investigation is performed in the small k (long wavelength) approximation. The solitons are found to be highly unstable with respect to the oblique perturbations. The dependence of the instability growth rate on the ratio of dust to plasma density is presented. The results apply to the lower ionosphere of Earth, the ionosphere of Mars in the vicinity of Phobos, as well as to the cvometary tails.

NP2.2 Nonlinear time series analysis

Convener: Kurths, J.
Co-Convener: Stark, J.

COMPLEXITY MEASURES FOR THE CHARACTERISATION OF NONLINEAR WAVE PHENOMENA IN PLASMA TURBU-LENCE

T. Dudok de Wit (Centre de Physique Théorique, CNRS and Université de Provence, Marseille, France)
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Concepts developed in the framework of dynamical systems have in the last decades had a strong impact on our perception of nonlinear phenomena in plasmas. Most analysis techniques, however, cannot be meaningfully applied to regimes of fully developed turbulence, which are high-dimensional and spatially extended. An exception is the concept of complexity, which involves the computation of entropies. Complexity measures are routinely used for symbolic dynamics but their application to experimental turbulent sequences is not as far along.

Here, we consider magnetic field fluctuations that have been measured in the vicinity of the Earth's quasiparallel bow shock. The properties of the wavefield vary with the orientation of the fluctuations; of particular interest are occasional monolithic structures that show a preferential orientation. Standard nonlinear time series analysis techniques do not clearly reveal their existence whereas complexity measures do. This example and the availability of fast algorithms make complexity measures powerful tools for analyzing nonlinear phenomena in plasma turbulence.

DETECTION OF CHANGES IN DYNAMICS USING SINGULAR SYSTEMS ANALYSIS

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Singular systems analysis (SSA, variants of this are known as principal component analysis or EOF analysis) is a widely used method to extract significant dynamical patterns or oscillations in complex or noisy data sets. Initially formulated to separate high-variance dynamics from uncorrelated (white) noise, Allen and Smith (1997) have modified the algorithm to separate dynamical processes from autocorrelated noise processes (e.g. red noise).

In this paper we apply this method to detect differences in dynamics between two datasets, one reference set and one test set. Instead of using a noise covariance matrix in the multi-channel SSA, the eigenvectors of the reference set from a standard M-SSA are used to "filter out" its dominant oscillation patterns in the test set before applying the M-SSA to this modified test dataset. The cases presented discuss changes in dynamics in complex chaotic baroclinic waves from laboratory experiments with a thermally-driven rotating annulus.

EMBEDDING OF COMPLEX SYSTEM TIME SERIES

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In recent decades, a variety of algorithms were developed to analyse nonlinear dynamical systems in phase space. Most remarkable is the work on reconstructing the attractors using univariate time series based on the embedding theorem. Usually, the Grassberger-Procaccia algorithm is used for identifying chaotic attractors. However, these algorithms normally require a very large and almost noise free data set in order to produce a reliable estimate of the dimension. This casts a certain doupt on the results of dimension analysis based on observations, especially the reports on low-dimensional climate attractors, since the correlation-dimension calculations are limited to dimensions less than 10 or 20. This, of course, is not adequate, when concerning the climate system. In this paper a new algorithm is presented, which allows to reconstruct the dynamics of complex systems. This can be done, because the demand on data-set number is much smaller, than it is for dimension calculations. In the presented algorithm the properties of sequences of reconstructed states are analysed. These sequences do not allow to estimate a correlation-dimension, but carry information on the dynamics. This inforamtion is used to determine the time delay and the embedding dimension. Furthermore, some properties of the dynamics may be estimated. This is demonstrated with various Lorenz-Systems and near surface temperature data from the atmosphere.

SPECIFIC ASPECTS OF LINEAR AND NONLINEAR ERROR EVOLUTION IN A BAROTROPIC MODEL

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The predictability of atmospheric flow is inherently linked to its stability with respect to small perturbations. Therefore, it is of interest to investigate growth of small errors in the initial state of atmospheric models. In general, that investigation requires consideration of nonlinear error evolution. However, the growth of small perturbations can, for certain lengths of time intervals, be described by tangent-linear models. Nevertheless, for given length of time interval, the accuracy of this tangent-linear approximation (TLA) deteriorates as initial perturbation size increases. To assess the accuracy of the TLA, it is necessary to define a norm that measures the magnitude of a perturbation. For a given norm, perturbations with special structure may rapidly amplify, whereas others might grow slowly or even decay. Here the accuracy of the TLA is investigated in detail with regard to its dependence on (i) structure of the initial perturbation (e.g. singular vectors), (ii) initial perturbation size, (iii) length of time interval, and (iv) norm measuring distance. We concentrate on the following issues: how different can estimates for the accuracy of the TLA become, when the above issues are varied? What is the nonlinear error growth saturation time? These questions will be addressed in detail for an hemispheric barotropic atmospheric model. The results confirm earlier studies of TLA-accuracy, but point towards the necessity to consider the above issues (i)-(iv) carefully. Approximations between the TLA and fully nonlinear error evolution will be briefly considered.

Nonlinear Analysis of Earthquake Data

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In the present work we analyze the phenomenon of clustering in time and space of earthquakes. To characterize the underlying spatio-temporal dynamics, we use a coarse-graining to get symbols which represents the local seismicity. The results of the nonlinear analysis of real earthquake catalogues are compared with model data.

FRACTAL FLOOD STATISTICS

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The flood intensity factor F is introduced as the ratio of the ten-year flood to the one-year flood. If floods obey fractal statistics then F is also the ratio of the 100-year flood to the ten year flood and the ratio of the 1000-year flood to the 100-year flood. In order to test the validity of the fractal flood frequency hypothesis we consider fractal fits to 41 year records for 1009 USGS streamflow stations that are unaffected by flood control projects, good fits are obtained. Consistent regional variations in the flood intensity factor are also found. The physical justification for the applicability of fractal statistics is that river flows can be approximated by fractional Brownian walks which are known to exhibit fractal extremal statistics.

STRUCTURE RECONSTRUCTION OF NONLINEAR DYNAMICAL SYSTEMS FROM OBSERVED TIME SERIES WITHOUT INFORMATION ON NOISES DISTORTED AN USEFUL SIGNAL.

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The method for the reconstruction of differential equations of dynamical systems based on the first order function of sensitivity is developed. The key factor of such approach is the special noise-cancelling methodology. It is demonstrated that the developed method can be used for reconstruction of differential equations in the case when its number is larger than the number of observed variables. The practical limits of the method to analysis of observed time series are found. A numerical applications to the Lorentz attractor, the 5th and 7th mode model of turbulence illustrate the theory.

FRACTAL ANALYSIS OF SIMULTANEOUS OBSERVATIONS OF PULSATING AURORA AND VLF-CHORUS

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Fractal features of auroral pulsations and VLF emissions are determined by the data of simultaneous ground-based measurements. The data used were obtained during cooperative Russian-Finnish experiments in 1993-95. The data digitized with 10 Hz frequency have been analyzed. It was found that at the different local time the VLF emissions mainly tend to white noise features. However, there are localized events when the data sets of the VLF emissions have the low-dimensional behavior ($3 \geq D_c \geq 2$). Such events have been found at the 4-5LT 27 and 28 Jan 1993. Multifractal analysis of these data sets lead to symmetrical shape of the singularity spectrum that give the possibility to estimate the probability by simple theoretical model of multifractal cascade. The auroral data usually have low-dimensional ($D_c<1$) structure at the high amplitude scales. For events mentioned above it has been found increasing of the dimension to $D_c \approx 4$ that is higher than one for correspondent VLF sets. Features of the magnetosphere processes that lead to such events are discussed. The using of different multifractal measures to analyze the data of simultaneous measurements is discussed.

IDENTIFICATION OF LOW-DIMENSIONAL NONLINEAR PROCESSES IN NOISY TIME SERIES

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Given a spatially distributed system the dynamics of which are dominated by the interaction among only a limited number of characteristic spatial structures the present study aims at constructing low-dimensional nonlinear models from a multivariate time series of the system contaminated with observational noise. The high-dimensional dynamical field is projected onto a linear subspace spanned by relatively few characteristic spatial modes called Principal Interaction Patterns. The expansion coefficients of these patterns are assumed to be governed by a nonlinear dynamical system depending on a set of free parameters specified within a suitably chosen model class based on some physical knowledge or reasoning about the underlying dynamical process. The optimal low-dimensional model is determined by identifying the spatial modes and the system parameters simultaneously from a time series of the system according to a nonlinear variational principle based on a dynamical optimality criterion using ensemble integrations. The performance of the method is demonstrated using numerically generated data.

TESTING FOR NONLINEARITY IN THE SOLAR WIND

Wiesław M. Macek and Lidia Obojska (Space Research Centre, Polish Academy of Sciences, Bartycka 18 A, 00-716 Warszawa, Poland)

We analyse a time series of the velocities of the low-speed stream measured by the Helios spacecraft in the inner heliosphere, which is a region of space dominated by the solar wind flow. We use moving average and singular value decomposition (linear) filters to give a faithful representation of the system's nonlinear behaviour. We have found that trajectories describing the system in phase space asymptotically approach the attractor of low-dimension. The obtained values are significantly different than the values computed for the surrogate data. Thus these results provide evidence that the inner heliosphere is likely to be a nonlinear chaotic system.

FROM NONLINEARITY TO PREDICTABILITY

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Detection of nonlinearity in experimental time series is usually based on rejection of a linear null hypothesis by a statistical test. Typically, the null hypothesis is a Gaussian process passed through a static nonlinear transformation or similar simple alternative. Rejection of such a null is frequently interpreted as a detection of deterministic nonlinear relation in data under study, which is, however, only one of possible alternatives.
We show how variable variances or seasonality in variance could lead to spurious detection of deterministic nonlinearity and discuss how to identify actual determinism in studied time series.

WEATHER AND SUN: CYCLES AND INTERMISSIONS

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To study the effect of the solar forcing on the climate, we represent the latter with a two state system (the Lorenz equations, suitably written) and force it with a model of the solar cycle variations. There are many parameters in such a description and we use them to investigate the effects of varying both the amplitude and the characteristic times of the driver, and especially the role of grand minima.

PROBABILITY STRUCTURE OF DYNAMICAL AMPLITUDES FOR A PURE POWER-LAW POWER SPECTRUM: THE ABSENCE OF CONVERGENCE TO A UNIQUE PROBABILITY DENSITY FUNCTION

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Power-law power spectra have been a source of confusion to time series analysists in recent years. For example the correlation dimension is found to converge, even though no connection with chaotic behavior can be made. In the present work we offer another unusual kind of behavior for systems which have power-law spectra and uniformly distributed random Fourier phases. We demonstrate that realizations of stochastic processes of this type have amplitude probability density functions which do not converge to any unique probability density function for a wide range of spectral indices. In fact the density functions are shown to be infinitely variable, i.e. each selection of uniformly distributed random phases yields a density function which is generally quite different from the others. These results are shown to be the source of a number of confusing interpretations recently obtained in the analysis of satellite altimeter data which very often leads to difficulties not only in the interpretation of the data, but also in terms of assessing the noise content of the measurements and in the use of conventional filter techniques to remove noise.

WAVELET ANALYSIS AND PREDICTION OF THE CURRENT CLIMATE CHANGE

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We consider wavelet transform as a new tool to analyse the chaotic and simultaneously nonsteady climatic air temperature time series of the global, hemispheric and regional scales. Significance of the conclusions about the current climate change and its evolution in future which are obtained on base of the wavelet transform of time series of interest are examined by means of comparing the wavelet transform patterns of the above real series with those of the surrogate ones. Especially, the problem of the detection of the GG signal on base of the interhemispheric delay of the current global warming is discussed. Then, we split the real time series onto statistically stationary oscillations and a trend-like component and create a special discrete mapping for the extrema of the oscillation that can be used in order to predict some next extrema with the lead time about a decade. The procedure admits to speculate that the current global warming can be checked during the end of the XXth c.

CRITERION FOR APPLICABILITY OF DYNAMICAL TIME-SERIES ALGORITHMS

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We consider the problem of the proper choice of processing technique for time-series data. It is known, that correlated random data may be interpreted as deterministic, and vice versa. To decide, whether a given time series should be processed by dynamical or statistical methods, we propose to used as a criterion the normalized slope of the correlation integral $\varphi(\epsilon, m) = m^{-1}d(\ln C(\epsilon))/d\ln\epsilon$, where m is the embedding dimension. It is shown that when φ does not tend to 0 on the resolved range of scales as m grows, then there will be serious limitations for dynamical methods even if the data are dynamical by nature. For high-dimensional attractors usually it is insufficient data to resolve small scales, and on large scales the delay reconstruction for any m mixes true and false neighbours of attractor points and therefore restricts the application of dynamical techniques, such as estimating Lyapunov exponents or predicting time series. As a result of this neighbours mixing, the whole dynamics looks random, and application of statistical techniques becomes more appropriate. The properties of delay reconstruction, which lead to the distortions of attractor structure and formation of false neighbours are discussed.

AN EXAMPLE OF THE CHAOS THEORY PRACTICAL IMPLICATION IN THE FORMULATION OF A DETERMINISTIC CLIMATIC MODEL

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Antun Marki, B.Sc., Assistant

Long series of temperature monthly means at Zagreb, Croatia, were subjected to the correlation algorithm. Some deformations on the cumulative frequency distribution curves indicated a possible existence of a low-dimensional subspace, which might describe large magnitude influences of just three coupled governing variables. When compared with some previous investigations at Zagreb climate, those variables most probably were: temperature, T, cloudiness, N and the received solar radiation, Q. Some attempts were made to formulate a closed system for those three variables. Due to a strong dependence of the received solar radiation on the cloudiness, the basic system could be reduced to two equations: a diagnostic one for the temperature climatic variations in dependence on Q and N, i.e. T(Q,N) and a prognostic equation for the cloudiness, N=N(t). Several scenarios of N(t) with respect to the general circulation of the atmosphere prevailing patterns over European mid-latitudes have been theoretically modelled to simulate expected temperature variations. The application to several locations in Europe gave encouraging results.

THE CHOICE OF METRICS IN PREDICTING MULTIVARIATE TIME SERIES

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Current operational weather prediction models numerically predict the evolution of the order 10^7 variables. Due to the existence of spatio-temporal correlations, however, not all of these variables can be considered to be fully independent and the true phase space has a smaller dimension but it can still be very large. In assessing predictive ability it is necessary to define a distance or metric in this space and there exist many possibilities. A general discussion will be made of the possible choices of metric and how these can influence the apparent predictability of such systems.

MODELLING OF THE IRREGULAR LOW-FREQUENCY OSCILLATION WITH VARIABLE PARAMETERS BASED ON THE APPROXIMATION METHOD FOR CLIMATIC TIME SERIES.

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Climatic time series usually constitute non-stationary processes that can be interpreted as a sum of systematic components or trend (Anderson 1976), and random components or noise. Systematic trend components are consited not pnly of the exponential trend component describing the proper climate changes, but also low-frequency (LF) oscillated components with unstable „flexible" parameters. It is, therefore, insufficient to apply a single method for analysis of unstable processes with complicated temporal structure. For detailed analysis of these processes it is necessary to use a number of different methods taking into account the ranges of the most efficient application of the every method and restrictions of the analysing data. To solve these problems we have elaborated an analysing technology and software METR (Mathematical Ergodisation of Temperature series) (Thernyschev et al., 1992, 1994) and applied it to investigated processes. The procedure for modelling irregular low-frequency oscillation is presented. This method was used for analysis of century trend of air temperature and precipitation during the period of instrumental observationd on the flat territory of the former USSR (Vygodskaya et al., 1995). The main elements of METR technology are demonstrated on the example of the temperature time series analisis.

DIMENSIONALITY ANALYSIS AND STRANGE ATTRACTORS OF TIME-SERIES ELECTROTELLURIC DATA.

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The field of non-linear dynamics has resulted in the development of several techniques aimed at determining the dimensionality of strange attractors underlying time-series data.
In the present contribution, we discuss the hypothesis that chaotic behaviour in the variations of electrotelluric field can be described by a non-linear dynamical system with a strange attractor.
The correlation dimension of the strange attractor of the underlying dynamical system is regarded as a characteristic of chaotic behaviour of the electrotelluric field. Furthermore, the prediction method introduced by Sugihara and May (1990) applied to electrotelluric data, measured in different areas of Greece.

STRANGE ATTRACTORS AND 3-D FRACTALS IN THE TIME SERIES OF THE PRECAMBRIAN BANDED IRON FORMATIONS (BIF)

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It is presently common knowledge that banding and folding in BIFs has a multiorder fractal structure. Geometrical fractal structures are often products of non-linear chaotic processes, and by analyzing nature data, we can find out from what kind of temporal evolution a certain signal derived. An analysis of 100 BIF's magnetic distributions using Takens method showed that spatial variations of magnetite are an exhibition of the deterministic time history of the ore systems. It is established that inclinations of the D=f(d) plots defining a fractal dimension of attractors D=2.05-2.3 (more precision calculation, an opposite of D=2.2-2.8 in the primary calculation). Unique geological and geophysical data of the Kirovogorskoye BIF deposit structures give a possibility to determine 3D fractal dimension of the BIF bodies (D=2.14). At the same time, 2D sections with different orientations have very identical dimensions (D=1.50-1.52), and this allows a conclusion to be made that the anisotropy of ore elements transport was absent in the course of the ore generating process. This means that magnetite distribution in the ore bodies after folding, metamorphism of BIFs, etc., is controlled and can be set by an interaction of a small number of variables.

THE EFFECTS OF ENSO ON THE HYDROLOGY AND ECOLOGY OF A PLEISTOCENE LAKE SYSTEM IN THE QDA. DE CAFAYATE, NW ARGENTINA

M.H. Trauth, K. Kleinert, M.R. Strecker, C. Guenter and R. Oberhaensli (Institut fuer Geowissenschaften, Universitaet Potsdam, Germany)

Varved Pleistocene lake sediments in the Qda. de Cafayate have been studied in great detail in order to evaluate the paleohydrological and -ecological changes in a lake system due to intra- and interannual precipitation chances. The varves, 1 to 10 mm thick, show a remarkable internal structure. The base of a single varve is sharp and defined by the deposition of reworked Fe-rich Tertiary sedimentary rocks associated with a background sedimentation of light-brown silt derived from adjacent metamorphic rocks. We interpret the hydrological perturbances as the result of a sudden fluvial influx of clastic material during torrential rainfalls in the annual rainy season in southern hemisphere summer. Index minerals are used to quantify the relative fluvial influx from these sediment sources within the catchment area. The exponential decrease of sediments with fluvial affinities suggests a delayed clearing of the water body during the dry season in fall and winter. Toward the top of the varves, a thin layer of pure diatomite documents the spring diatom bloom within the clear and nutrient rich lake. In almost every fourth to fifth layer, the sudden influx of more Tertiary source material appears to be more intense. As this region lies within a sensitive zone which is affected by the El Nino/Southern Oscillation (ENSO), we interpret the sediment section to reflect extreme ENSO phases. Furthermore, interannual changes in precipitation in the catchment area and therefore, changing fluvial influx, hydrochemistry and nutrient supply in the lake are also documented in drastic changes in diatom assemblages.

TIME SERIES ANALYSIS BY ESTIMATING OPTIMAL TRANSFORMATIONS FOR NONLINEAR REGRESSION

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We use a recently developed tool from statistical analysis [L. Breiman and J. H. Friedman (1985)] for the analysis of uni- and multivariate time series, for which this method can be utilized most advantageous. In our approach, several tasks of time series analysis are solved by estimating optimal transformations for nonlinear regression of suitable chosen variables derived from the time series. The procedure to estimate the optimal transformations is based on a *parameter-free* alternating least square algorithm.

We apply the method to the reconstruction of differential-delay equations from short and noisy data, to forecasting of time series, and to multiple-input causality analysis.

Finally, some unusual properties of this method are discussed briefly.

Characteristic Scales in Earthquake Data

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We present a new technique in order to quantify the dynamics of spatially extended systems. Using a test on the existence of unstable periodic orbits we detect intermediate spatial scales, wherein the dynamics is characterized by maximum nontrivial determinism. We apply our method to earthquake catalogues containing time, co-ordinates and magnitude. As a result we extract a set of areas with clear deterministic and low-dimensional dynamics from the data. Finally, we use a simple model to show that the scales can be interpreted as a spatial coupling strength.

NP3.2 Geophysical turbulence

Convener: Read, P.L.

NOISE-SUSTAINED STRUCTURES IN QUASIGEOSTROPHIC TURBULENCE

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Although the influence of small noise on large scale fluid dynamics is expected to be small, dealing with ocean turbulence however random inputs of energy could be organizer by nonlinear interactions into large scale currents following isobaths when bottom topography is present. The origin of these large scale ocean currents comes by the interaction of noise, nonlinearities and the underlying topography. We have studied the mechanism of generation of these noise-sustained structures in an idealized ocean dynamics described by a viscous quasigeostrophic model where small scales are modelized by random noise. A coarse graining procedure (i.e. droping out the small scales but taking into account their dynamical influence on large scales) has been employed to get the large scale dynamics. As a result of this procedure, we have obtained that the effect of the interaction between small scales (noise), topography and nonlinear terms is to force the large scale components to follow isobaths. The manifestation of this internal forcing in the large scale equations of motion is through the appearence of a modified viscosity operator of the same form as some heuristically suggested parametrizations. Finally, numerical experiments have been carried out to test the theory.

GEOSTROPHIC TURBULENCE IN AN INTERNALLY HEATED, ROTATING FLUID ANNULUS WITH SLOPING END WALLS.

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In this paper we report new experiments on free thermal convection in a rotating fluid annulus, subject to internal heating and side wall cooling, in which a radial depth gradient has been created by the inclusion of oppositely sloping boundaries. End wall configurations that cause the fluid depth (D) to increase with radius ($\partial D/\partial r > 0$) and to decrease with radius ($\partial D/\partial r < 0$) have both been studied. When the boundary slope (δ) is small, no difference is observed in the range of azimuthal wavenumbers ($m = 3$ to 7) seen in the regular wave regimes of the two end wall configurations. At larger values of δ, however, this symmetry is lost, with regular modes $m = 2$ to 8 ($m = 1$) being observed with $\partial D/\partial r > 0$ ($\partial D/\partial r < 0$) end walls. The zonal mean flow is found to develop a significant barotropic component, superimposed on the vertically and horizontally sheared zonal jets generated by the non-monotonic thermal gradient of the experiment. This barotropic component is predominantly prograde (retrograde) in the $\partial D/\partial r > 0$ ($\partial D/\partial r < 0$) end wall experiments, and confined close to the outer (inner) wall where the fluid depth is greatest. There is evidence of the formation of increased numbers of zonal jets in the $\partial D/\partial r > 0$ end wall experiments above that expected from the form of the thermal forcing. These multiple zonal jets are highly localised in the vertical, and are trapped close to the top boundary. Their radial scale is, nevertheless, close to that given by the Rhines argument. No comparable increase in the radial wavenumber of the mean flow is observed in the $\partial D/\partial r < 0$ experiments in the present system.

THE STRUCTURE OF THE VORTICITY FIELD IN LOW FROUDE NUMBER STRATIFIED TURBULENCE

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Tony. Maxworthy (Department of Aerospace Engineering, University of Southern California, Los Angeles, California, USA)

The structure of the vorticity field of freely decaying stably stratified turbulence in the low Froude number regime is experimentally investigated for late times with a high resolution Correlation Image Velocimetry system (CIV). Quasi-2D vortices seperated vertically by strong horizontal vortex sheets are quickly formed. As the buoyancy scale u/N approaches zero the vorticity field remains highly 3D as strong vertical shearing between structures promotes a horizontal alignment of the vorticity vector, and is responsible for most of the viscous dissipation of energy in this collapsed state.

VELOCITY STRUCTURE IN DECAYING TURBULENCE

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The variation of the velocity moments and structure functions in decaying non-homogeneous turbulence produced by a grid is investigated by means of a sonic velocimeter SONTEK3-D . We also study the probability density function variations as a function of distance from the grid for each component of the turbulent velocity using two different methodes : The histogram method and the moving window method. The variation of the moments of the velocity and their ratios, as well as the evolution of the structure functions defined in terms of the spatial and temporal velocity diferences indicate the changes in the structure of the turbulence as it decays away from the grid. A basic parameter in order to characterize the structure of the turbulence is the ratio of the structure function moments of order p+1 and p as a function of p. Some information is also given by the evolution of the ratios of velocity distribution moments. The variation of temporal correlation Re(t) and of the spectrum, determines further the variation of integral lenthscales, which increases with the distance from the grid. In Geophysical flows, there are many instances, where turbulence is originated locally, such as surface wave breaking at the surf zone or by internal wave breaking in the lee of a mountain, The use of velocity structure functions and their moments may give an indication of the distance and time delay from the source of turbulence.

TOPOLOGY OF VORTEX MOTIONS OF FLUID IN HARBOR-LIKE BASINS AT LARGE REYNOLDS NUMBERS

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It has been observed for a long time that under certain conditions a vortex and even a group of vortices form in bays which have a narrow opening to the sea. What leads to the formation of such vortices confined in a quiet, almost closed bay? Why does their number vary? The answers to these questions are essential in practice, because, if several vortices form in a bay, a sort of a "vortex-cork" is created which prevents the outflow of pollution from the bay. This work considers the topology of the vortex regimes generated in harbour-like basins by the external potential long-shore current at large Reynolds numbers. The theory discusses the issues of what solution may be realized as an asymptotic state of the open hydrodynamical system. The analysis is developed based on the variational principle, modified for the open degenerated hydrodynamical system. It is shown that the steady state corresponds to the circulational regime in which the system has minimal energy and enstrophy. This state is fixed by the Reynolds number. The relation between the Reynolds number, the geometry factor and the topological number, characterizing the number of vortex cells, is found.

DYNAMICS OF VORTEX DIPOLES EMITTED INTO RIVER MOUTH

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Results of analysing dynamics of vortex dipoles in rivers mouths are presented. Main purpose is construction of the possible scenarios. their classification and definition of geophysical parameters for really observable phenomenon of emitting dipole vortex structures from river mouths into open ocean. The investigation within the framework of a simplified model have shown that if the river inflow is simulated by a point source of constant potency. the considered process will be realized only in narrow mouths with half-angle less than $\pi/4$. Two topologically various kinds of motion trajectories are possible for the vortex dipoles outgoing from a source. If the their energy is more than defined threshold value. the vortices move along open trajectories. which asymptotically go into straight lines parallel to a bisectrix of the mouth angle. and abandon the river mouth. Otherwise the vortices move along closed trajectories without escaping from the river mouth.

3-WAVE WHISTLER DECAY PROCESS NEAR BOW SHOCK

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In paper [1] the turbulence in the foot region of quasiperpendicular Earth bow shock with great Alfven Mach number and $\beta \sim 1$ have been investigated on the basis of "Prognoz-10" satellites measurements. The elementary 3-wave decay process with the participation of whistlers and ion cyclotron waves was identified. In present work the dynamics of such process is considered. The set of equations for 3-wave process ($i = 1,2,3$) taking into account self- and cross-modulation and 2D nonlinear diffraction has the form:

$$\frac{\partial E_i}{\partial t} + \overrightarrow{V}_{Gin}\frac{\partial E_i}{\partial \overrightarrow{r}_n} + \frac{1}{2} i \frac{\partial^2 \omega}{\partial k_l \partial k_m}\frac{\partial^2 E_i}{\partial r_l \partial r_m} = \alpha_i E_j E_k + i(\beta_{i1} \mid E_1 \mid^2 + \beta_{i2} \mid E_2 \mid^2 + \beta_{i3} \mid E_3 \mid^2)E_i,$$

where V_{Gi} -the group velocity of the waves, E_i– their amplitudes.
For definite direction of wave vector of decaying whistler (relatively to magnetic field) all possible decay channels in 2D geometry are considered. The characteristic nonlinear times of decay are calculated and the channels with maximum probability of decay are defined. The comparison with experimentally obtained [1] decay conditions is presented.

[1] S.A. Romanov, S.I. Klimov, P.A. Mironenko Kosmicheskie Issledovaniya ("Space Research"), 1990, v. 28, 903-918. (In Russian)

THE NONLINEAR DIFFERENTIAL EQUATIONS GOVERNING A HIERARCHY OF SELF-EXCITING COUPLED FARADAY-DISK HOMOPOLAR DYNAMOS

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The derivation of the novel nonlinear ordinary differential equations that govern the behaviour of a hierarchy of self-exciting Faraday-disk homopolar dynamo systems driven by steady mechanical couples is outlined. Each system comprises N interacting (in general dissimilar) units, within each of which are electric motors driven into motion by the dynamo. Dissipation is due not only to ohmic heating bot also to mechanical friction in the disk and the motors, with the latter playing an unexpectedly crucial role, especially in the production of chaotic fluctuations (Hide, *GRL* **22**, 1057, 1995; *PEPI*, 1997; Hide, Skeldon & Acheson, *PRS* **A452**, 1369, 1996). A mechanism for triggering magnetic field reversals is indicated by the waveforms of multiple periodic non-harmonic fluctuations that occur under certain conditions. Of particular interest are investigations of phase and amplitude locking in the more complicated cases that arise when $N > 1$. Even the least-complicated members of the hierarchy, with N as low as 1, 2 or 3, could prove useful as simple (but not over-simplified) physically-realistic low-dimensional models of fluctuating stellar and planetary magnetic fields. Geomagnetic polarity reversals could be affected by the presence of the Earth's solid metallic inner core, driven like an electric motor by currents generated by self-exciting magnetohydrodynamic (MHD) dynamo action in the liquid outer core.

POTENTIAL MAGNETIC FIELD AND POTENTIAL VORTICITY IN MAGNETOHYDRODYNAMICS

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New general expressions have recently been given extending theorems governing the behaviour of the *potential vorticity* (Ertel) pseudoscalar in continuum mechanics and *potential magnetic field* (Hide) in electrodynamics (*GJI* **125**, F1, 1996). The laws of thermodynamics are readily incorporated into the expressions by choosing *potential temperature* as one of their arbitrary scalars. The expressions can be used to provide succinct derivations of theoretical formulae employed in the determination of motions in the Earth's liquid core from geomagnetic secular variation data and in related geomagnetic investigations. They should find wide application in prognostic and diagnostic studies of basic magnetohydrodynamic processes, such as those underlying the magnetic fields of the Earth and other planets and of the Sun and other stars, especially in the evaluation of the results of numerical simulations.

LAGRANGIAN ACCELERATIONS IN STRATIFIED GEOSTROPHIC TURBULENCE

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P. Klein (Laboratoire de Physique des Oceans, IFREMER, BP 70 29280 Plouzané France)

The Lagrangian accelerations in stratifed geostrophic turbulence are analyzed both analytically and in numerical simulations on the β-plane. The accelerations are induced by the torque which is exerted on the geostrophic flow by the ageostrophic velocity field. The three-dimensional particle dispersion is governed by the eigenvalues of the three-dimensional gradient tensor of the accelerations. The determinant of the latter is the Hessian of the ageostrophic streamfunction and potential. Numerical simulations illustrate this point.

A LOW-ORDER MODEL OF BAROTROPIC FLOW BASED ON PRINCIPAL INTERACTION PATTERNS

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A low-dimensional dynamical model (10-20 degrees of freedom) capturing the principal properties of turbulent barotropic flow is constructed. Given a spectral model of the barotropic vorticity equation truncated at wavenumber 21 the system is projected onto a linear subspace spanned by only a limited number of characteristic spatial structures called Principal Interaction Patterns. The expansion coefficients of these patterns are assumed to be governed by a dynamical system of the Lorenz type, i. e. a forced, dissipative system with quadratic nonlinearity. The nonlinear interactions are designed in a way that the quadratic term in the reduced model conserves kinetic energy and enstrophy. The optimal low-dimensional model is determined by identifying the spatial modes and the interaction coefficients simultaneously from a time series of the high-dimensional spectral model according to a variational principle based on a dynamical optimality criterion. This leads to a high-dimensional nonlinear optimization problem which is solved numerically using an adjoint technique.

THE TOPOGRAPHIC ARREST

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Stratified, geostrophic turbulence over a sloping bottom is considered. When the slope is weak (by a measure defined herein), a Rhines-type spectral arrest halts the inverse cascade. The final flow is thus approximately barotropic and anisotropic, oriented along the isobaths. When the slope is strong, the cascade ceases at the deformation radius, and the final flow is predominantly surface-intensified, and isotropic. The strong slope scenario arguably bears a closer resemblance to oceanic flows; the implications are discussed.

SUBGRIDSCALE EDDY PARAMETRIZATION BY STATISTICAL MECHANICS OF POTENTIAL VORTICITY

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Evgueni Kazantsev and Jacques Verron (LEGI, BP 53X, 38 041 Grenoble Cedex, France)

The feasibility of using a subgrid scale eddy parametrization, based on statistical mechanics of potential vorticity, is investigated. A specific implementation is derived for the somewhat classical barotropic vorticity equation in the case of a fully eddy-active, wind-driven, mid-latitude ocean on the β-plane.
The subgrid scale eddy fluxes are determined by a principle of maximum entropy production, so that they efficiently drive the system towards statistical equilibrium. In the absence of forcing and friction, the system then reaches equilibrium, while conserving all the constants of motion of the inviscid barotropic equations. We show that this equilibrium is close to a Fofonoff flow, like obtained with truncated spectral models, although our statistical approach is different.
We then validate our subgrid scale model in a more realistic case, with wind forcing and friction. The results of this model at a coarse resolution are compared with reference simulations at a resolution four times higher. The mean flow is correctly recovered, as well as the variability properties, such as the kinetic energy fields and the eddy flux of potential vorticity. Generalization to multilayer baroclinic flows are discussed.

NP3.3 Vortex dynamics

Convener: Dritschel, D.G.
Co-Convener: Zeitlin, V.

A NEW DETERMINISTIC APPROACH TO INTERMITTENCY IN TURBULENCE

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N. Obregón (Hydrology, University of California, Davis, CA 95616, U. S. A.)

The construction of a vast class of deterministic derived measures over the line , defined as transformations of simple multinomial multifractals via fractal int erpolating functions, is reviewed (Puente, 1992). It is illustrated that these objects, which are projections of unique measures l iving in the graphs of fractal interpolating functions, provide a new framework to study intermittency in turbulence. Examples are given which show that these measures have power and singularity spe ctra which match those found in nature. In regards to energy dissipation rates in fully developed turbulence, it is demo nstrated that it is possible to define measures having the observed intermittenc y structure (i.e. via the p-model) which bypass entirely the notion of a casca de, as they are found transforming a uniform measure via a suitable fractal interpolating funct ion. It is argued that the concept of projection may be key to understand the dynamic s of intermittent sets.

THE EQUILIBRIUM SURF ZONE

R. Alan Plumb (Dept. of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology)
L.M. Polvani (Dept. of Applied Physics, Columbia University)
Adam Sobel (Dept. of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology)

We will describe the equilibrium state of a well-mixed "surf zone" in a shallow water model of the winter stratosphere. It is assumed that the surf zone is well-mixed (i.e. that potential vorticity is almost uniform), and that a non-trivial equilibrium is maintained by weak thermal relaxation (or, more accurately, by thickness relaxation in the shallow water model that mimics thermal relaxation in the stratosphere). In the equilibrium state, in which the time scale for potential vorticity transport by Rossby wave "mixing" is assumed to be much shorter than the relaxation time scale, vortex erosion by wave breaking must almost cease. Moreover, the potential vorticity fluxes, and consequent forcing of the zonally averaged circulation, within the surf zone are formally no larger than beyond its boundaries. This has implications for the forcing of the Brewer-Dobson circulation in the stratosphere, though it is not clear to what extent the stratosphere ever attains such an equilibrium structure during the course of a winter.

Laboratory experiments on the interaction of two oppositely-signed shielded monopolar vortices.

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The results of laboratory experiments on the interaction between two closely generated, quasi two-dimensional, shielded, monopolar vortices will be presented. The experiments are performed in tank filled with a step-wise stratified salt solution. It is shown that the vorticity shielding provides an important mechanism in bringing both monopolar vortex cores closer together resulting in the formation of a dipole vortex, consisting of two closely packed patches of opposite vorticity. However, when the distance between the vortices is too large, no dipole formation takes place and the vortices are observed to become tripoles and show only weak interaction. The velocity field is determined by tracking neutrally buoyant tracer particles at the interface using a video camera mounted above the tank and an image processing system. Flow visualization of the dipole formation is also obtained by the injection of dyed fluid.

ON THE TRANSFER OF TRACER BY EDDIES ON THE BETA-PLANE

E.S. Benilov (Department of Mathematics, University of Tasmania, P.O. Box 1214, Launceston 7250, Australia)

The problem of the evolution of tracer "injected" in an eddy on the beta-plane is examined numerically using the pseudospectral method. The eddy is governed by the standard quasigeostrophic equation, and the tracer is governed by the transfer equation (with no diffusive term). At the initial moment of time, the streamfunction describing the eddy and the distribution of the tracer are both radially symmetric. It is demonstrated that the tracer rapidly looses radial symmetry and forms coherent spiral patterns; whereas the potential vorticity (which satisfies exactly the same transfer equations), as well as the streamfunction, remain almost perfectly symmetric! It turns out that this phenomenon has a simple theoretical explanation based on the "potential vorticity thinking". Similar spiral patterns were observed in the cases where the tracer was initially concentrated in a "strip" or elliptic "spot". In the latter case, the tracer field looked very similar to the cloud patterns in tropical cyclones.

STATIONARY VORTICES IN THREE-DIMENSIONAL QUASI-GEOSTROPHIC SHEAR FLOW

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An existence theorem for localised stationary vortex solutions in an external shear flow is proved. The flow is three-dimensional and quasigeostrophic. The domain is unbounded, and the external flow is a linear shear flow whose strength varies linearly with height. The flow conserves an infinite family of Casimir integrals. Flows that have the same value of all Casimir integrals are called *isovortical flows*, and the potential vorticity- (PV-) fields of isovortical flows are *stratified rearrangements* of one another. The theorem guarantees the existence of a maximum energy flow (i.e. an energy maximising stratified rearrangement) in any family of isovortical flows that statisfies the following conditions: the PV-anomaly must have compact support, it must have the same sign everywhere, and this sign must be the same as the sign of the external shear over the vertical interval to which the support of the PV-anomaly is confined. This flow represents a stationary and localised vortex, and the maximum-energy property implies that the vortex is stable. The PV-anomaly decreases monotonically outward from the centre of the vortex, but apart from this the profile is arbitrary.

VORTICES IN A SHEARED NEAR-WALL FLOW: A KINETIC APPROACH

E.S. Benilov (Department of Mathematics, University of Tasmania, P.O. Box 1214, Launceston 7250, Australia)

Purporting to model weak hydrodynamic turbulence, I consider an "ideal gas" of point vortices in a two-dimensional flow bounded below by a wall. The velocity of the flow is linearly sheared and positive (i.e. directed "to the right"); the density of vortices at infinity (far away from the wall) tends to a constant backgrownd value. A kinetic equation for the density of vortices vs. distance from the wall is derived and solved numerically. The results indicate that: (i) the density of clockwise rotating vortices gradually decreases towards the wall (by about 13% as compared to the backgrownd density); (ii) the density of counter-clockwise rotating vortices first grows (by about 14%), but then, at a certain distance from the wall, vanishes.

MEAN FIELD PREDICTIONS OF NON-LINEAR ω-ψ-RELATIONS IN 2D TURBULENCE

Hanna Brands, Rubén Pasmanter, Wim Verkley.

At sufficiently high Reynolds numbers, the formation of coherent structures in freely decaying two dimensional incompressible flows eventually results in a quasi-stationary state, i.e. a structure that is stable and stationary, apart from slow dissipation by viscosity. It has been proposed by several authors that this dynamics can be understood from the maximization of entropy, constrained by the conservation laws of the dynamical equations.
In the inviscid case there is an infinite number of constants of the motion, to wit, the areas on which the vorticity takes specific values. In the statistical mechanics of these inviscid flows these are accounted for by an infinite family of Lagrange multipliers. The applicability of this theory to weakly dissipative flows is not obvious, since the relevance of the inviscid constants of the motion is not clear in this case.
A number of researchers have tried, with varying success, to characterize the quasi stationary states that result from numerical simulations and laboratory experiments of weakly dissipative flows by solutions to the equations of the statistical mean field. However the effects of viscosity are not easy to assess so that important questions remain which relate to the predictive power of the theory and the range of its applicability with respect to initial and boundary conditions.
In this presentation we focus on numerical calculations that produce quasi-stationary states with non-linear ω-ψ-relations. We will study the initial and boundary conditions that produce such relations, and make a comparison between the numerical calculations and the corresponding statistical mechanical predictions.

AN ANALYTICAL SOLUTION FOR THE TRIPOLAR VORTEX.

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R. Ford (Dept of Mathematics, Imperial College, Queen's Road, London SW7 2BZ, UK)

Tripoles are often observed as fairly stable vortical structures in rotating fluid experiments and numerical simulations of two-dimensional flows, and are also seen in oceanic observations. Unlike the dipole, there is no known analytical solution for the tripole in the absence of external shear. We construct such a solution from a perturbative expansion of the stable monopolar profile $J_O(\lambda r)$. It is demonstrated that the relation between vorticity and streamfunction must be nonlinear. We compare the analytical solution with numerical solutions and we hope to discuss the stability at finite amplitude.

MULTIPOLAR BAROCLINIC GEOSTROPHIC VORTICES

X. Carton, S. Corréard and B. Forgeau (SHOM/CMO, Brest, France)

In-situ measurements and satellite imagery have allowed the identification of complex baroclinic vortices in the Bay of Biscay (the "Swoddies", discovered by Pingree and LeCann, 1992). Here we model the stability and evolution of such baroclinic vortices in a two-layer quasi-geostrophic model. It is shown analytically and numerically that shielded, surface-intensified vortices can be baroclinically unstable to elliptical disturbances, and yield baroclinic dipoles and tripoles in nonlinear numerical models. Among these tripoles, oscillating as well as stationary structures are found. It appears that steady baroclinic tripoles possess a nonlinear potential vorticity vs streamfunction relation. Finite-area, piecewise-constant PV analogues of these stationary tripoles are searched, and point-vortex models are used to assess their stability. Environmental factors, such as beta-effect or bottom topography, can severely disturb such tripoles. These nonlinear evolutions are strikingly similar to those observed in the ocean.

CONTOUR DYNAMICS WITH NON-UNIFORM BACKGROUND VORTICITY

H.J.H. Clercx, G.J.F. van Heijst, R.M.M. Mattheij, P.W.C. Vosbeek (Dep. of Physics and Dep. of Mathematics and Computing Science, Eindhoven University of Technology, P.O. Box 513, 5600 MB Eindhoven, The Netherlands)

Often, *contour dynamics* is used to simulate (interactions of) vortices in two-dimensional, inviscid flows with zero or uniform background vorticity. The continuous initial vorticity distributions of the vortices are then replaced by piecewise uniform distribtutions. Since the evolution of a patch of uniform vorticity is fully determined by the evolution of its boundary, the evolution of the vortices can be obtained by following the boundaries of the uniform-vorticity-regions in time. In this presentation, it will be shown how contour dynamics can be applied to flows with non-uniform background vorticity, for example on the β-plane and the γ-plane. In addition, some numerical results will be presented.

QG 3-D heton dynamics and deep-ocean convection modeling

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D. Olbers, T. Warncke (Alfred-Wegener Institute for Polar and Marine Research, Am Handelshafen 12, 27570 Bremerhaven, Germany)

Dynamics of three-dimensional (3-D) localized disturbances of potential vorticity (PV) in a uniformly stratified rotating fluid is considered. We apply the quasigeostrophic (QG) potential vorticity equation using a point vortex approximation for PV field specified for the case of heton-like vortex structures. 3D heton is defined as a pair of coupled baroclinic vortices of the same strength and opposite signs located at different depths. We discuss some aspects of heton behavior on the example of 2 and 3 hetons and analyze fundamental properties of interaction between hetons. Numerical experiments are also made with population of hetons to simulate the spreading stage of turbulent convection with rotation. Regimes of confinement and of hetonic splitting are found and investigated. In particular, it is found that the splitting behavior essentially depends on vertical distribution of PV and the ratio of the local Rossby radius to the internal Rossby radius. Comparison between 3D-hetons simulations and LES modeling are performed.

MAXIMUM ENTROPY VORTICES IN TWO-DIMENSIONAL TURBULENCE

Pierre-Henri Chavanis and Joël Sommeria (Ecole Normale Superieure de Lyon, Lab. de Physique, 46 al. d'Italie, 69364 Lyon Cedex 07, France)

We explain the formation of isolated vorticity structures in two-dimensional turbulence as maximum entropy states. The entropy maximization (entropy mixing) is restricted to a freely deformable "bubble" of active fluid surrounded by irrotational fluid. We solve this variational problem in a limit of strong mixing, for which the relationship between vorticity and stream function is linear. In this limit, entropy maximization is equivalent to a form of enstrophy minimization. Then the optimal states depend only on the total circulation, energy, linear and angular momentum. Moreover we find that the structure depends only on a single control parameter, related to these conserved quantities. Dipoles or monopoles can be obtained depending on this parameter, and we classify these optimal states. Our result is a kind of generalization of Leith's minimum enstrophy vortices to non-axisymmetric cases, but we propose technical modifications to Leith's approach even for axisymmetric cases. We discuss the applications to the vortices emerging from two-dimensional turbulence. In particular we propose a collision law for monopoles.

THE INFLUENCE OF THE 3D POTENTIAL-VORTICITY DISTRIBUTION ON THE ALIGNMENT OF GEOSTROPHIC VORTICES

S. Corréard, X. Carton (SHOM/CMO, Brest, France)

Following Valcke and Verron (1993, 1995, 1996), we assess how varying initial distributions of potential vorticity influences the alignment of geostrophic vortices. In a two-layer quasi-geostrophic model, we consider the nonlinear evolution of two initial disks of relative vorticity, one in each layer. When stratification and intercentroid distance are changed, the initial PV distribution is strongly modified vertically by vortex stretching and horizontally by spreading and overlapping of opposite-sign poles. These multipolar effects noticeably alter the (alignment versus corotation) diagram described by Polvani (1991). In particular, horizontal and vertical dipoles are formed, which counteract alignment. An accelerated alignment regime is also found, as well as regular alignment and corotation. Each regime is analyzed in terms of PV distribution and corotating streamfunction (critical points). Simple point vortex modeling is used to illustrate dipolar versus corotation evolutions. Finite-area steady states are found, among which a novel feature of geostrophic vortex dynamics: a stationary baroclinic tripole. Applications to oceanic vortex dynamics are finally proposed.

NEARLY-CONSERVATIVE VORTEX DYNAMICS AND TURBULENCE AT FINITE ROSSBY AND FROUDE NUMBERS

D.G. Dritschel (Department of Applied Mathematics and Theoretical Physics, University of Cambridge, Silver Street, Cambridge, CB3 9EW, England)

New results have recently been obtained for the behaviour of a nearly-conservative rotating, stratified fluid, from quasi-geostrophic to strongly ageostrophic conditions. These results have been generated by a novel, highly accurate numerical algorithm, called the *contour-advective semi-Lagrangian* algorithm, which enforces conservation of potential vorticity (PV) by utilising a contour representation, as in *contour dynamics*, but which obtains the advecting velocity field and additional wave fields (height and divergence) by utilising a conventional grid representation. The new results include: (1) a demonstration that the tall-column instability, originally found in quasi-geostrophic flow, operates at finite Rossby and Froude numbers (the implication is that two-dimensional models are not valid at scales below the radius of deformation); (2) simulation results for nearly-conservative, rotating, stratified turbulence at finite Rossby and Froude numbers; and (3) an illustration that smooth gradients of PV (e.g. the planetary vorticity gradient) generally give way to sharp gradients bounding nearly uniform regions of PV as a consequence of weak forcing and recurrent instability.

INTERACTION OF TURBULENCE AND LARGE-SCALE VORTICES IN INCOMPRESSIBLE 2D FLUIDS

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In 2D fluid dynamics, intense large-scale vortices are modified by turbulence. Both the large-scale vortex and the turbulent components are important in their interaction : the vortices modify the turbulent dynamics and, in turn, are modified by turbulence. Using Wigner functions, we develop a two-fluid model to describe interaction of turbulence and intense large-scale vortices in incompressible inviscid 2D fluids. This model gives an analytic solution for the dynamics of a vortex dipole propagating through turbulence. We use this formulation to build a Large Eddy Simulation where small and large scales are computed respectively whith a Particles in Cell and a spectral method. We compare analytic and numerical results for a vortex dipole and present computation in more complex cases. We discuss generalisation of this model to rotating turbulence to desribe astrophysical or geophysical situations.

AN INVESTIGATION OF A VORTEX STREET BEHIND A HEATED CYLIN DER

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Is experimentally shown, that the heating of a cylinder, streamlined by a flow of air, results in a increase of distance of formation vor tex to it and in increase of their intensity. Effect of space growth of a pulsations of temperature in a trace for a heated up cylinder is found out. Theoretical model of a vortex street of a path at a heated up cylinder, enabling to explain these effects is constructed.

This work was supported by the grant RFBR (project code 96-02-16834).

VORTICES IN THE STEWARTSON LAYER

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Secondary instabilities of fully developed fronts have a major effect on these weather systems, and are increasingly studied. These instabilities often arise from a horizontal wind shear, and they are very difficult to predict in operational weather prediction.

This study presents laboratory experiments on the nonlinear dynamics of vortices in a shear zone in a rotating fluid. The shear flow is forced by differentially rotating concentric circular sections of the base and lid of the tank, thus setting up an internal shear layer as initially studied by Stewartson (1957).

When the Stewartson layers become unstable, a wave-like string of vortices grows to a finite amplitude. The main focus of this paper are time-dependent, modulated vortices and transitions to highly irregular flows, presumably three-dimensional turbulence.

CORIOLIS AND CENTRIFUGAL EFFECTS IN AN ANNULAR CELL WITH TIME-DEPENDENT FORCING

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In this work, we present experimental results concerning an oscillatory Ekman layer in a confined geometry. We study the Ekman layer developing under a periodically back and forth moving plate, which is confined laterally by two narrow cylinders. The measurements are performed by ultrasound Doppler velocimetry, which allows to obtain instantaneously the velocity profile along the vertical rotation axis. We present results concerning the evolution of the velocity with time over one period, and also as a function of the axial direction and for four radial positions. The second part of the work deals with the effect of the Coriolis force on centrifugal instabilities. The experimental configuration is a Taylor-Couette geometry with both cylinders rotating jointly with the same angular velocity, which is a mean rotation plus a periodic forcing to produce instability. The instability appears as counter-rotating Taylor vortices, which are visualized with Kalliroscope flakes. The instability threshold is studied as a function of the forcing frequency and of the Rotation number, which balances the mean rotation to the amplitude of the modulation. We have shown that for all modulation frequencies, the flow is first destabilized as the Rotation number increases and progressively stabilized at larger uniform rotation, corresponding to a Taylor-Proudman effect that inhibits the three-dimensionnal centrifugal instability.

BAROTROPIZATION OF VORTICAL FLOWS IN A ROTATING MULTILAYER FLUID

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In geostrophic turbulent flows there is an energy transfer, both, to larger scales due to the merging of like-sign vortices, as well as from baroclinic to barotropic modes by the alignment of vortex structures in the vertical. This barotropization process occurs preferentially at scales close to the Rossby deformation radius R (e.g. Rhines, 1979 and Salmon, 1981). The underlying dynamics of this barotropization process as well as the significance of this process to the evolution of geostrophic turbulence is a not yet understood.

The present experimental study focusses on the alignment of isolated vortices generated at different levels in a rotating stratified fluid. Monopolar vortices are generated by sources and sinks. Quantative information about the flow is obtained by using the particle tracking method. The influence of a single interfacial vortex on the motion in other layers in a rotating three-layer stratified fluid is studied for different ratios between the buoyancy forces of the two interfaces. Subsequently, the interaction between two vortex structures located at different interfaces is studied. Aspects of the energy tra nsfer during the alignment from the barotropic mode to the baroclinic mode are considered for both interfaces.

MONOPOLE-TOPOGRAPHY INTERACTION WITH A 2D NUMERICAL MODEL

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Field observations have confirmed the existence of Meddies: isolated drifting eddies containing water from the Mediterranean Sea. These subsurface vortices have an anticyclonic rotation and drift at typically 1 – 2 km per day. As they do so, they encounter complex bottom topography that affects their dynamics. Along the western coast of Portugal, for example, trajectories of acoustically-tracked floats trapped within the Meddies reveal clearly the steering effect of submarine canyons, the shelf edge itself and significant ridges such as the Gorringe Bank.

A two-dimensional numerical model is used to study this interaction, where the Meddy is modelled by a monopolar vortex. The numerical code solves the 2D viscous Navier-Stokes equation, including effects of topography and background rotation, in the vorticity-streamfunction formulation with a finite difference method. The use of a finite difference method prohibits sharp gradients in the topography, yet the method is quite suitable for studying the basic properties of interactions between monopolar vortices and topography.

DYNAMICS OF VORTEX PAIRS IN A STRATIFIED FLUID

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The motion of a vortex pair in a density-stratified, non-gravitating fluid is studied using an asymptotic theory developed earlier for description of the evolution of localized vortices. Provided the initial density variation ($\rho(\mathbf{r}) = \rho(y)$) is given in the first-order approximation the asymptotic scheme reduces to a system of integro-differential equations for vortex parameters. In the "frozen"(neglecting the shift of liquid particles of different densities under the action of moving vortices) approximation, for the cases of a smooth stratification and of a sharp density jump, this system reduces to a set of fourth-order ODE, which may be solved in quadratures. Analysis of these solutions shows, in particular, that, when the pair moves under a small angle to the horizontal plane, it is typically reflected from denser layers of the fluid. The parameters of the trajectories depend on the initial orientation of the pair axis [?], while the magnitude of vorticity in the vortex cores affects only the velocity of motion along the trajectories. For non-monotonous dependence $\rho(y)$, a resulting density channel may localize the motion of the pair along the channel axis. The difference between the cases of smooth and sharp density variations is that in the latter case, a vertical distance between the vortex cores remains constant in the course of motion. The problem considered is relevant to various geophysical situations, such as the behaviour of thermics formed by explosions in the atmosphere and vortex dipoles generated due to internal or surface wave breaking in the ocean.

ON A MODEL FOR QUASI-EQUILIBRIUM STRUCTURES OF FORCED TWO-DIMENSIONAL TURBULENCE

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We consider stationary forced two-dimensional turbulence, where the vorticity should be dissipated due to a linear friction. Supossing dynamical quasi-equilibrium between forcing and friction the formation of the large scale vorticity structure can be understood in the frame of solution of a linear elliptic differential equation which has to fulfil additional balance constraints for the kinetic energy E, total circulation Γ and enstrophy Γ_2. We test this model on the case of a turbulent vorticity field in a box which is driven by a single positive source. Then the theory predicts the formation of a large scale counter clockwise rotating annular vortex. Comparisons with results from direct numerical simulations show remarkable quantitative agreement with respect to the predicted stream function, vorticity distribution, and balanced intergral quantities (Theory: $E = 10.7$, $\Gamma = 20.0$, and $\Gamma_2 = 454$; DNS: $E = 10.0$, $\Gamma = 18.8$, and $\Gamma_2 = 438$).

SUPPRESSION OF INTENSE ATMOSPHERIC VORTICES

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The quite new method of suppression of tropical cyclones, hurricanes, typhoons, and tornadoes is presented. The possibility of active affection with respect these intense vortices is based on the Electromagnetohydrodynamic (EMHD)-mechanism of their intensification. According to this mechanism heat energy of the uprising from the ocean surface moist air is converted in the electric field energy, which via the EMHD-mechanism is converted in the kinetic energy of intensive eddy motion of a tropical cyclone and the energy of a powerful thunderstorm as a result of the EMHD-mechanism action is converted in the kinetic energy of intensive rotary air motion in a tornado. It is known that a mature thunderstorm has two main layers containing negative and positive charges. Inside it the potential gradient attains 10^6 Vm^{-1}. Herewith, the total charge of any sign in a hurricane of average dimensions has a value 10^7-10^{10}C. This electrical features and the EMHD-mechanism create very high forces which play the main role in formation and intensification of intense atmospheric vortices.
Suppression of these vortices can be realized by means of the discharge initializing with microwave or/and laser beams. The estimation results of selection of the preferable parameters of an electromagnetic beam such as frequency, power density, transmitting antenna sizes, and others are presented.

EXPERIMENTS ON FORCED TURBULENCE IN A STRATIFIED FLUID

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The flow produced by turbulent forcing at the boundary of a density stratified fluid is studied experimentally. The forcing consists of an array of radially directed sources and sinks located at one horizontal level. The turbulence generated at the sources is constrained to be two-dimensional by the stratification, and the flow becomes organised into a pattern of quasi-two-dimensional vortices. High-resolution measurements of the velocity and vorticity fields, obtained by particle tracking velocimetry, are used to gain an understanding of the structure and dynamics of the flow.
For rotationally-symmetric forcing, the flow becomes organised into a central vortex which grows to nearly fill the flow domain. This vortex has an interior with almost uniform vorticity and is shielded from its surroundings by high vorticity gradients. There is little exchange of fluid with the surroundings, but the vortex is maintained, against the effects of viscous dissipation, by the intermittent entrainment of vorticity of like-sign originating from the sources. The sinks play only a passive role. The sign of the central circulation is a consequence of any initial bias in the forcing.
The effect of non-rotationally-symmetric forcing and details of the vertical structure of the flow will also be reported.

INTERNAL WAVES AND POTENTIAL VORTICITY IN A CONTINUOUSLY STRATIFIED FLUID

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We report on a numerical study of the dynamical evolution of a three-dimensional progressive internal gravity wave in a linearly stratified Boussinesq fluid subject to a perturbing noise. The wave normally breaks following a stage during which secondary unstable modes grow via non-linear interactions at the expense of the initial wave. A diagnostic splitting of the velocity field in two parts, one associated with potential vorticity (vortex mode) and the remaining part associated with internal waves only, reveals that energy is transferred from the wave part to the vortex mode of the flow in the course of time. The object of this study is thus to investigate the interaction between the vortex mode and the internal wave field and to assess the importance of potential vorticity in internal wave breaking processes.

INTENSE ATMOSPHERIC VORTICES: ELECTROMAGNETOHYDRODYNAMIC NATURE OF INTENSIFICATION

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Intensification of tropical cyclones, hurricanes, typhoons, and tornadoes is one of the most important and while the not yet resolved problem of meteorology. For more than 150 years numerous attempts have been undertaken to solve this problem. However, understanding of physical processes causing their intensification is so far still away. At the same time, practically in all executed researches, as it not strange, is ignored the fact, that arising and development of intense atmospheric vortices occurs in an extremely strong electric field which together with the electromagnetohydrodynamic (EMHD) interaction plays the main role in their intensification. Obviously, the unilateral analysis of intensification of these vortices without the account of all physical processes can not result in understanding of laws of this complex phenomenon and in creation of satisfactory mathematical models.
On the basis of a new approach the detailed description of the EMHD model of tropical cyclones, typhoons, hurricanes, and tornadoes is presented. The model provides understanding of main processes which transform thermal energy of moist air to electric field energy and then via the electromagnetohydrodynamic interaction to kinetic energy of intense atmospheric vortices. This model is based on the famed observation data. Results of performed estimations are in good agreement with real conditions of their development.

SPIRAL VORTICES

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The general feature of various flows with intensive swirling is in existence of spiral (or helical) structures. This paper presents = the results of experimental and theoretical studying spiral structures of differ ent types. Depending on the geometrical parameters o= f the hydraulic vortex chamber the following phenomena are detected and describe d by us: vortex core precession; vortex filament gen= eration; stationary left-hand and right-hand helical vortices; vortex with chang ing helical symmetry; double helix-two entangled vor= tex filaments of the same sign; vortex breakdown and waves on vortices. The theo retical model based on the assumption of helical sym= metry allowed to predict and explain some of the above enumerated phenomena.

ON THE MOTION OF A VORTEX ON A BETA-PLANE. PART I: EVOLUTION

S.-L. Lam and D. G. Dritschel (DAMTP, Cambridge CB3 9EW, UK)

The long-term evolution of an initially circular vortex patch of radius R under the equivalent barotropic quasi-geostrophic approximation is, for the first time, studied using a Contour-Dynamical scheme called Contour-Advective Semi-Lagrangian (CASL) algorithm (Dritschel & Ambaum, 1997). This has been made possible by the particularly high efficiency of this algorithm compared to the classical Contour Dynamics. In our model simulations, the β-plane is discretized into a number of equally-spaced steps of potential vorticity. This permits a remarkably high resolution of the fine-scale structures. Meanwhile the large-scale flow features are in good agreement with previous simulation results. Several numerical experiments have been done for the cases $R/RDR \ll 1$ and $R/RDR \approx 1$ (where RDR is the Rossby deformation radius) with different vortex strengths. It is found that the vortex is more vulnerable to instability with increasing R/RDR as it is on a f-plane. In particular, a coherent tripolar structure emerges from a vortex of intermediate strength when $R/RDR \approx 1$.

ON THE MOTION OF A VORTEX ON A BETA-PLANE. PART II: BETA-DRIFT

S.-L. Lam (DAMTP, Cambridge CB3 9EW, UK)

The self-induced migration (β-drift) of an initially circular vortex patch of radius R on a β-plane is investigated by direct numerical solutions of the equivalent barotropic quasi-geostrophic equations. The advantage of this model lies in the fact that the residual flow due to the redistribution of the ambient potential vorticity and the flow due to the distortion of the vortex boundary can be extracted precisely. Both are proved crucial to the β-drift and the stability of a vortex moving on the β-plane. Various numerical experiments are carried out for the cases $R/RDR \ll 1$ and $R/RDR \approx 1$ (where RDR is the Rossby deformation radius) with different vortex strengths. Of particular interest is the extraordinarily large meridional displacement demonstrated by a vortex of intermediate strength during the period after sufficiently many turn-around times but before reaching its rest latitude. This phenomenon is explained by examining the intensity and the orientation of the residual flow, which depends, respectively, on the vortex strength and on the tendency for the residual flow to rotate opposite to that of the vortex while they propagate as a whole.

COASTAL FLOW BIFURCATION CONTROLLED BY TOPOGRAPHY

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The stationary solutions for coastal flow past an escarpment are considered in both the quasi-geostrophic and shallow water models. Analytical solutions are obtained in the case of an exponential coastal current profile. These solutions are compared to numerical simulations that follow the evolution of the flow starting from a state of no motion. The position of the coast with respect to the escarpment is essential to determining whether a simple bifurcation of the current, with one branch followi ng the escarpment and the other following the coast, will occur. If the orientation is such that when looking from deep to shallow water the coast is on the right, then such a bifurcation is possible. Otherwise, the stationary solutions would require inflow along the escarpment, which is unrealistic without an additional source of flow. These results are confirmed by the numerical simulations.

HAMILTONIAN FINITE-DIMAENSIONAL MODELS OF BAROCLINIC INSTABILITY

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A hierarchy of N-dimensional systems is constructed starting from the standard continuous two-layer quasi-geostrophic model of the geophysical fluid dynamics. These models ("truncations") preserve the Hamiltonian structure of the parent model and tend to it in the limit $N \to \infty$. The construction is based on the known correspondence $SU(N) \to SDiff(T^2)$ when $N \to \infty$ between the finite-dimensional group of unitary unimodular $N \times N$ matrices and the group of symplectic diffeomorphisms of the torus and the fact that the above-mentioned continuous model has an intrinsic geometric structure related to $SDiff(T^2)$ in the case of periodic boundary conditions. A fast symplectic solver for these truncations is proposed and used to study the baroclinic instability.

Laboratory Experiment of the Polar Voltex Reversal

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Experimental Apparatus

A rotating dishpan experiment showed the reversal phenomena of the initial westerly polar voltex. The dishpan was set up from a water tank with a parabolic basin and a distorted sylindorical side wall. This experimental apparatus is a simulation tool of hemispheric barotropic fluid motions.

Experimental Results

At first, westerly hemispheric polar vortex was uniformly rotating, then the initial vortex was deformed by the polar ward (center ward) propagation of stationary planetary waves with zonal wave number 1 or 2 which were excited at the lower latitude side wall. And finally, the higher latitude westerly polar vortex changed the direction toward the easterly vortex, although the lower latitude polar vortex kept the westerly direction. The experiments were practiced in various Rossby numbers which were defined as the ratio of the initial westerly angular velocity and the system rotation.

Consideration

Strength and area of the polar vortex reversal are discussed in the relationship with the quantity and the pattern of mixture of the initial potential vorticity. This experiment suggests the wave number dependency in the Stratospheric Sudden Warming phenomena.

INVESTIGATION OF VORTEX AND WAVE EFFECTS OF ATMOSPHERIC CONDENSATION ON FORECAST OF CYCLONE ORIGINATION AND THEIR MOVEMENT

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Laboratory modelling of atmospheric vortices induced by chemical reactions in the rotating liquid, which imitate dynamic effects of heat release during condensation in the atmosphere, was carried out. We have found conditions of origination hurricane type vortices. It is shown that self-induced motion of the vortex due to its internal asymmetry is responsible for appearance of complex trajectories. Comparison with theoretical and field data was done. We have proposed a theory of generation and amplification of infrasound during atmospheric condensation of water vapour in intense cloud formations. We have also carried out laboratory modelling of infrasound generation Helmholtz resonators filled by supersaturated vapour. Comparison of theoretical results with laboratory and field data have shown that amplitude variability of infrasound pressure pulsations is a short-term predictor of cyclone intensification.

A FAST ALGORITHM FOR LINEAR STABILITY ANALYSIS

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A fast algorithm for normal mode analysis is presented for the investigation of linear stability of coherent vortex structures. In this iterative method, for a given basic state, a set of most unstable modes is extracted through filtering out the less unstable modes, sampling at regular time intervals, orthogonalising, and solving a small eigenvalue problem. This is an adaptation for real-valued evolution operators of the method of Goldhirsch, Orzsag and Maulik (*J. Sci. Comp.* 2, 1987). The algorithm is implemented in a high-resolution vectorised pseudo-spectral code, and is applied to the barotropic vorticity equation on a sphere linearised about a stationary modon basic state. Much higher resolution can be reached compared with solving the full eigenvalue problem directly, and several of the most unstable modes rather than a single mode of the tradition time-integration method can be obtained, with a precise estimate the accuracy, and in a much shorter integration time.

The new algorithm enables for the first time quantitative research into the decay modes of coherent structures in dependence of their parameters such as size, location and resolution. By tracking competing normal modes while varying the parameters of the structures, different regimes can be distinguished separated by 'phase transitions' where one normal mode takes over another. Thus, homotopies can be studied from parameter space into the discrete set of amphidromic points that characterise each normal mode. This is demonstrated for modons, stationary dipolar solutions of the inviscid unforced barotropic vorticity equation on a sphere, with a piecewise linear relationship between potential vorticity and streamfunction in two regions separated by a boundary circle.

This research is part of SWEEP, a comprehensive programme on coherent structures, balanced models, and topology and geometry of flow domain manifolds, in the fields of atmospheric science, fluid dynamics, plasma dynamics, nonlinear science and theoretical physics. Further information on internet: http://www.atm.damtp.cam.ac.uk

DYNAMICS OF VORTEX MERGING IN 2D FLOWS

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The merging of two equally signed monopolar vortices has been investigated in detail by numerically solving the two-dimensional Navier-Stokes equations using a high resolution double-periodic spectral code. The influence of the vorticity distribution in the vortices on the interaction process was stu died by using Gaussian as well as patch-like vortices. The dynamics is vizualized by high pass filtering of the vorticity field together with the Weiss field. It is found that in the spiral filaments created during the merging process the vorticity dominates the strain rate. On the boundary of the compound vortex resulting from the merging, however, the straining is dominating. The relation between the enstrophy "cascade" and the evolution of spiral vorticity filaments in developed 2D turbulence is discussed. Following the evolution passive tracer particles we observed that a significant part of particles originally trapped in the two initial vortices is scattered in the spiral filaments. For the particles trapped in the compound vortex the mixing is more effective for the Gaussian vortex profile, since here the spiral filaments extent almost to the vortex center. Further differences between the two initial conditions will be discussed.

VORTEX DYNAMICS FROM THE PERSPECTIVE OF THE PERIODIC INVERSE SCATTERING TRANSFORM IN 2 + 1 DIMENSIONS

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The Kadomtsev-Petviashivili equation is studied as a model for integrable vortex dynamics in two-dimensional fluid flows. The inverse scattering transform is used as a spectral description of the nonlinear dynamics of N dimensional, energy conserving vortex interactions. The approach is then extended to higher order dynamics for which the motion is still found to still be integrable. The linear dispersion relation of these flows is found to provide substantial improvement over that at lower order. The nonlinear spectral description is characterized in terms of the theta function formulation of the inverse scattering transform. Therefore the vortices are found to belong to a particular parameter range of the nonlinear basis functions of IST. Thus the vortices may be viewed as a kind of nonlinear component of the IST formulation. In the general case where vortices undergo inelastic interactions I show that the period matrix has natural temporal variations, whose ordinary differential equations are specified and whose solutions are given in terms of Poincare' series. I give numerical examples of the interactions of a number of vortices.

STORMY WEATHER ON A POINT VORTEX PLANET

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D. G. Dritschel (DAMTP, Cambridge CB3 9EW, UK)

We consider the dynamics of strong, localized vorticity concentrations in a barotropic flow on a rotating sphere with a midlatitude jet. This system is meant to provide a simplified model of the dynamics of storm systems; we study both the statistics of storm lifetimes and the interaction with a simplified topographic obstacle. The system dynamics is simulated by both a point-vortex model and a contour advection CASL scheme on the sphere.

Canonical variables for 2D Vortex Dynamics

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The Hamiltonian structure related to the 2D hydrodynamics of the ideal incompressible fluid is studied. It is shown that the corresponding Poisson bracket is reduced to the Gardner-Zakharov-Faddeev bracket for monopoles and dipoles. The new coordinates have a clear geometrical meaning: Cartezian coordinates of the poles and the set of distances from them to the vorticity lines. A connection between canonical variables and the contour dynamics is discussed.

LAGRANGIAN DYNAMICS IN POINT-VORTEX SYSTEMS

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J. C. Mc Williams (Dept. of Atmospheric Sciences, UCLA, Los Angeles, USA)
J. B. Weiss (PAOS, University of Colorado, Boulder, CO, USA)

We study the dynamics of point vortex systems with periodic boundary conditions, in both the pure Hamiltonian case and when punctuated mergings are allowed. We discuss the statistical behavior of Lagrangian velocities and the single-particle dispersion properties. A comparison with random dispersion models is considered.

PLANETARY WAVES IN CONTINUOUSLY STRATIFIED OCEAN OF VARIABLE DEPTH

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Rossby waves in stratified ocean with constant N over corrugated rough-bottomed topography are considered. There exist three types of modes: topographic mode, barotropic mode, and a countable set of baroclinic modes. For small relative height d of the bottom bumps the barotropic and baroclinic modes are transformed into the "usual" Rossby modes in an ocean of constant depth and the topographic mode degenerates. With increasing d the barotropic and baroclinic frequences increase monotonically and these modes become close to purely topographic mode. As for the baroclinic modes, their frequences do not depend on d in the order of magnitude. For large d the "displacement" effect takes place when the mode velocity becomes small in a near-bottom layer and the baroclinic mode does not "feel" the actual bottom relief. As in the two-layer model, the "screening" effect implies that the small-scale component of the modes is confined to a near- bottom boundary layer if the horizontal topography scale is smaller than the Rossby scale.

ON THE INTERACTION OF HETONS DURING THEIR CONTRARY COLLISION

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The work examines the problem of the interaction of two baroclinic vortices - *hetons* during their contrary collision within the limits of a quasi-geostrophic model of two-layered ocean on the f - plane. Calculation results for discrete vortices are compared with the results for distributed vortex patches. The last ones are obtained by the Contour Dynamics Method. The influence of Rossby deformation radius value and sizes of vortex patches on the character of newly formed stationary states are discussed. In particular, as the result of the grazing collision of two distributed hetons, we have obtained some connected state - *whirligig* - two-layered analogue of tripolar structures.
The work is fulfilled due to support of INTAS (Grant 94-3614) and RFBR (Grants 95-05-14972, 96-05-66265).

A DIAGNOSTIC MODEL OF GIANT, STABLE VORTICES IN THE JOVIAN ATMOSPHERE

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The atmosphere of Jupiter is dominated by a number of giant, coherent oval vortices at the level of the visible cloud layers. These features were observed in some detail at, and above, the cloud tops, by the Voyager and (currently) the Galileo spacecraft, though their nature and details of their vertical structure remain highly uncertain. Also, attempts to model these phenomena have so far been carried out only in the context of highly approximated sets of dynamical equations (quasi-geostrophic or shallow-water theory), and assume extremely simplified forms for their vertical structure. In the present study, we have applied the technique of balanced potential vorticity inversion using the full time-independent meteorological primitive equations, in combination with currently available observations of Jupiter's Great Red Spot and White Ovals in the Jovian upper tropopsphere and stratosphere, and plausible inferences for the vertical variation of static stability to a depth of $\sim$ 100 bars. This hybrid approach is then used to derive self-consistent, steady, axisymmetric fields of potential vorticity anomaly, consistent with a range of possible vertical structures for these vortices beneath the visible clouds. The vortex structures associated with the range of solutions obtained with this model will be presented, and possible implications of the different cases for future modelling strategies will be discussed, with particular regard to interactions with thermodynamic processes in Jupiter's troposphere and the circulation of its deep interior.

VORTEX DYNAMICS BEHAVIOUR IN PRESENCE OF A SLOPE USING A 2D QUASI-GEOSTROPHIC MODEL

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The purpose of this study is to understand the dynamics of a current flowing along the coast in presence of a topographic slope perpendicular to the coast-line.
A quasi-geostrophic model, without stratification, is used and numerically solved by means of a finite-difference direct simulations. Free-slip conditions are imposed for the coast-line, a suitable velocity field is imposed to simulate the coastal jet, radiative conditions are used for the remaining boundaries.
We have analysed two different cases: flow passing from shallow to deep water and viceversa. Moreover the variation of the width and height of the slope is considered.
The more interesting phenomena observed are the following: the bifurcation of the current when the flux passes from deep to shallow water and the formation of a dipole when the flow passes through the slope from shallow to deep water. These results are in agreement with previous laboratory experiments in a rotating tank. Also the formation of dipoles over the topography may be relevant to the observation of dipolar structures in the surface temperature field off the southern coast of Sicily.

MONOPOLAR SOLITARY VORTICES IN BAROTROPIC AND BAROCLINIC DIFFERENTIALLY ROTATING FLUID

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We study the problem of large- scale (of the order of or larger than the deformation radius) monopolar vortices in differentially rotating fluid. We identify several asymptotic regimes close to the quasi-geostrophic balance for the behaviour of such structu res depending on the mutual relations among the Rossby number, Burger number and the non-dimensional gradient of the Coriolis parameter (β) in shallow-water, multi-layer and continuously stratified models, respectively. We confirm our theoretical predictions in a laboratory by studying a shallow fluid layer in a rapidly rotating paraboloidal tank and using a special measurement techniques. Two clearly different dynamical regimes are observed. The first one corresponds to the well-known quasi-geostrophic behaviour of the weakly nonlinear monopolar vortices and is dominated by the Ros sby wave radiation and a noticeable meridional component of the drift velocity while in t he second one strongly nonlinear large scale vortices are drifting strictly westwards maintaining their coherence for a long time.

VERTICAL ALIGNMENT OF GEOSTROPHIC VORTICES WITH THIN CORES

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The evolution of near-by, like-sign vortices whose centers are at different vertical levels in a stably stratified, rotating fluid is studied in two differently singularized representations of the quasigeostrophic equations for vortices with uniform potential vorticity cores. An analytically tractable, conservative (Hamiltonian), elliptical-moment model for thin-core vortices is shown to capture the strong elongation of vortex cores in response to horizontal strain that is an early evolutionary stage towards merger and alignment. This interpretation is strengthened by comparison with dissipative numerical solutions of a thin contour-dynamics representation, which can exhibit further progress towards these vortex transformations. Both the elliptical-vortex and contour-dynamics models show qualitatively similar regime boundaries between evolutions with weakly and strongly deformed vortex cores. In particular, there is a fairly close correspondence between the occurrence of strong core elongation in the elliptical-vortex solutions and significant filamentation and splitting in the contour-dynamics solutions.

HYDROLOGICAL AND DYNAMICAL CHARACTERIZATION OF MEDDIES IN THE AZORES REGION: A PARADIGM FOR BAROCLINIC VORTEX DYNAMICS.

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During the Semaphore experiment, hydrological data, currentmeter recordings and float trajectories were collected over a 6-month period (june-november 1993), in a $500 * 500 km^2$ domain south of the Azores. This data exhibits three intrathermocline eddies of Mediterranean water (meddies). We quantify here their hydrological and dynamical properties on isopycnic surfaces. Intense temperature and salinity anomalies (up to $4°C$ and $1 psu$), vertically ranging over 1000m and centered around $1000\,dbar$, are associated to these meddies. Horizontally, these anomalies spread out to radii of 50 to 60 km, though the maximum azimuthal velocities lay at around 35 km. The heat, salt and potential energy contents of these meddies thus significantly contributed to the mesoscale transports and dynamics in the region. Indeed, these meddies followed bent trajectories, with drift velocities up to $10\,cm/s$, under the influence of the neighboring mesoscale features (companion cyclones or jet meanders). The analysis reveals the complex three-dimensional structure of potential vorticity in and around the meddies: one of them was coupled to a subsurface anticyclone, forming an aligned vortex (Polvani, 1991). It later interacted with the Azores front, creating a large-amplitude northward meander by vertical alignment of vorticity. South-east of the front, another meddy was horizontally sandwiched between an Azores front meander and a cyclone of large vertical extent. This cyclone later interacted with a stronger cyclone and underwent a partial merger (Dritschel and Waugh, 1992; Yasuda, 1995). To explain the meddy interactions with the Azores jet, we finally use a simple quasi-geostrophic model in which analyses can be performed with a finer time-sampling.

VORTEX-TOPOGRAPHY INTERACTION

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We study the interaction of a barotropic, cyclónic vortex on a β-plane with a topographic slope by means of laboratory experiments and a finite differences numerical model to solve the nondivergent barotropic equation. In the laboratory, the eddy is produced in a rectangular rotating tank with a weak sloping bottom (3.5°, also called topographic β-plane) in order to simulate the β-effect. The vortex moves to the northwest and interacts with an additional pronounced linear topography (35°) in the western boundary of the tank. Results show that the original northwest trajectory changes to the south until the vortex is dissipated. As it moves uphill, the exterior ring of the vortex forms a strong current to the northeast. From this current a new cyclon is created, repeating approximately the behaviour of the original one. Later, a second and a third vortices are formed in the same way. Despite the presence of the strong slope, agreement with numerical runs suggests that conservation of potential vorticity is the basic mechanism involved.

VORTEXES IN A VICINITY OF AN ISLAND IN A TIDAL SEA

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In frame of barotropic quasi-geostrophic model on a f-plane with the horizontal turbulent mixing the generation of vortexes in secondary Euler currents in a vicinity of a circular mesoscale island (20-50 km) in a tidal sea of a constant depth is investigated. The horizontal tidal movement of water is small in relation to the diameter of an island and it has a reversible character.The solution is obtained by matched asymptotic expansions. It is shown that boundary layers around an island have one- or two-layer structure. One-layer structure has the Schlichting viscous layer only and two-layer structure has the inertial-viscous layer in addition to viscous one. The bifurcation period of tidal waves separates these two cases. The inertial-viscous layer has separation points and therefore it cannot exist as a whole around an island.

The research was supported by Grants RFFR (No.95-05-14972 and 96-05-66265) and by Grant INTAS (No.94-3614).

TOPOGRAPHIC EDDIES IN A STRATIFIED OCEAN

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In frame of the quasi-geostrophic model of a stratified ocean on a f- and beta- plane the generation of topographic eddies in sheared currents is investigated. Among their member two-layer currents with opposite flows in layers are considered. Modified beta-effect on a beta-plane and the pseudo-beta-effect on a f-plane lead to the generation of lee waves in these currents. The necessary radiation conditions are described. It is shown that for these two-layer currents topographic eddies are localized near the level where the current velocity is equal to zero but not near a bottom. Therefore in this case the topographic eddy looks most likely as a lens but not as a classical Taylor-Hogg's cone.

The research was supported by Grant RFFR (No.95-05-14972) and by Grant INTAS (No.94-3614).

NP4.2/NH6 Coherent structure and natural hazards

Convener: Moiseev, S.S.
Co-Convener: Mendes-Victor, L.A.

TWO-PHASE MODELS OF GRAVITATIONAL AVALANCHE-TYPE FLOWS

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The problem of construction of the mathematical models describing the motion of gravitational avalanche-type flows considered as two-phase continuum media is discussed. These flows are: snow avalanches (snow and air), debris flows (water and debris material), slushflows (snow and water). The equations of mass and impulse conservation for each phase and for the whole mixture are written. The phase transitions are excluded. A term due to phase interaction takes into account in dynamic equations. This term is assumed proportional to a difference of phase velocities for avalanches and debris flows. The one-dimensional hydraulic type model based on averaged all quantities over cross section of flow is presented for debris flows. The liquid phase is modeled with a viscous fluid and the phase of debris inclusions is considered like a dry continuum media. It is convenient to treat slushflows within frameworks of two-layered model, namely the upper layer presents the floating snow in water and the lower one is a pure water. The interaction between these layers and entrainment of new snow mass into flow are taken into account. Two-layered model of mixed-type snow avalanche allows to study an occurrence and evolution of a powder cloud due to mixing with air on the top of flowing snow. A friction and mass transfer between layers are taken into account. Two-phase models permit to estimate a diffusion of phases in flows and to explain a series of effects, in particularly, the retardation of debris phase and a run away water along deposition zone and so on. The results of numerical modelling are given.

ON THE HELICITY GENERATION IN SHEAR FLOWS IN THE EXTERNAL MAGNETIC FIELD

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E. Golbraikh and A. Eidelman (Center for MHD Studies, Ben Gurion University, P.O.B.653, Beer-Sheva 84105, Israel)

We have studied helicity generation in magnetohydrodynamic (MHD) systems with a mean flow and external transverse homogeneous magnetic field ($\mathbf{B}\|\mathbf{z}$). It is shown that the presence of transverse gradient of the mean flow velocity ($v_o\|x$) along y- and z-axes is a sufficient condition of the appearance of non-zero helicity in such a system. We compare the obtained results with experimental data on MHD flows received under laboratory conditions and in the Earth's atmosphere.

LABORATORY SIMULATION OF HELICAL TURBULENCE AND POLLUTION TRANSFER IN THE ATMOSPHERE

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Experimental study of anisotropic turbulence generated under constraint in magnetohydrodynamic flow revealed a similarity in its energy spectra and wind spectra exponents. Theoretical investigations of helical turbulence have led to the interpretation of these results, particularly, -7/3 exponent, local disturbances, etc., in the framework of the helical model. Numerical simulation of atmospheric pollution transfer taking into account -7/3 velocity spectral scaling has revealed a respective change in passive scalar dispersion scaling. The computation of the pollution transfer parameters under such turbulence shows an essential difference from the case of -5/3 Kolmogorov's turbulence. The comparison with the available data of atmospheric observations shows their good agreement with modeling results.

SCALING PROPERTIES OF RADIOBRIGHTNESS TEMPERATURE FIELD OVER TROPICAL CYCLONES

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The data processing of radiobrightness temperature fields over tropical cyclones at the square of 400x400 pixels are performed. The studying of scaling properties o f RBT-fields representing the large-scale coherent structure and small scale chaot ic subsystem is given on the basis of space structural functions and generalized dimensions analysis at the space scale from 2.5 km to 750 km. The existence of inertial range with power law dependence is demonstrated and scaling exponents a re calculated. The comparison with background RBT-foeld (outside typhoon) is made. The data processing result is interpreted using the physical concept of natural haza rds diagnostics elaborated early in IKI RAS.
Support of this work was provided by th e RF Ministry of Science and Technical Policy (grant Vortice-2).

GRAVITO-ELECTRODYNAMICS OF DUST IN AN ELECTRIC CUSP

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An electric cusp or electrically neutral point (line or sheet) is analogous to a magnetic cusp and has been introduced by the author with the concept of electric field line merging-reconnection for the last decade. It has been shown that any perturbation exerted on an electric cusp, typically the injection of dust into a cusp can lead to electric field line merging-reconnection. In other words, the source-origin of electric reconnection is an electric cusp that becomes a bifurcation point for the electric potential and at the same time a saddle point for the electric field, necessarily being capable also for a source-origin of chaos. In this paper, additional perturbation by an external gravitational field is considered, in particular focussing on how the behaviour of dust in an electric cusp will be modified by an external gravitational field, namely 'gravito-electrodynamics of dust for tenuous plasmas is discussed with its relevance to laboratory and cosmic dusty plasmas. The criterion of ordered and chaotic behaviours of dust grains in a periodically cusped structure is indicated. As a complementary study, electric potential and field profiles for the case when a spherical or cylindrical dust is placed in a point or line cusp are obtained in detail.

ALLOCATED IMPERFECTIONS OF DEVELOPED CONVECTIVE STRUCTURES

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It is well known, that in nonequilibrum convective mediums are formed periodic (in real mediums, such as atmosphere or mantle of the Earth, solar crown etc., quasiperiodic) structures. Their formation, as a rule, has a threshold character and is connected with exceeding of Rayleigh number Ra of some critical value Ra_1. The amplitude of an arising primary structure thus is proportional to $\epsilon_1 = (Ra - Ra_1)/Ra_1$. During growth of a primary structure there are appear the conditions for development of secondary instability (of modulation type), which leads to formation of large-scale regular imperfections, embedded in the primary structure. By analogy, it is possible to enter a control parameter of secondary instability R_2, to determine its critical value R_2 and level of its above-threshold. Obviously, R_2 is function of intensity of a primary structure. Easily to show, as in the appropriate time scales, ϵ_1 and ϵ_2 are the increments of the appropriate instabilities.

Analysis of behaviour of some nonlinear systems (in particular, con-vective unstable layer of a liquid with the rigid boundaries poorly conducting heat [1]) has shown, that a ratio of intensities of developed secondary and primary structures (the so-called imperfection level of a primary structure) appears about ϵ_2. The same order relation takes place between a characteristic scale of a primary periodic structure and characteristic size of a regular imperfection.

NUMERICAL ANALYSIS OF LARGE-SCALE CONVECTIVE MOTIONS IN A THIN FLUID LAYER WITH THERMALLY INSULATED BOUNDARIES

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Results of numerical solution to the equations of a semiempirical model (it has been presented at XXI General Assembly of the European Geophysical Society) for turbulent convection by the finite difference method are presented. The mathematical model considered describes the generation of the large-scale vortices in a thin fluid layer. This process is caused by the action of anomalous heat transfer mechanism, which manifests itself under conditions of high intensity of small-scale turbulent convection and low level of heat loss through boundaries. The influence of various physical factors (the small-scale turbulent convection intensity, the degree of boundaries heat insulation, the rotation, the intensity and form of initial heat perturbation, and etc.) on large-scale instability evolution has been investigated. The obtained results have been compared with our earlier theoretical predictions and with our experimental data on laboratory modeling of tropical cyclones, and have verified them. This work is supported by RFFI under Grant N 95-01-01094a.

AMPLIFICATION OF FLUCTUATIONS AND CURRENT DYNAMO DUE TO HELICAL AND CHIRAL EFFECTS IN GEOPHYSICAL AND PLASMA-LIKE MEDIA

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It is well known that in conducting medium with small-scale helical turbulence generation of large-scale magnetic field is possible. But it has not been so far taken in account that correlation function of microcurrents must also have helical part. The present work consider more general case, when not only mean motion but also conducting components possess nonzero mean helicity. Dispersion equation for helical motions is studied, including inhomogeneous case. Criteria for development of instability are found.

Further in the work chiral media are considered and effects topologically close to helical ones are analyzed. It is shown that in such media ranges of waves exist, in which fluctuations can be anomalously amplified.

Behaviour of conductivity in fluctuating media with helical and chiral effects as well as influence of ponderomotor forces on mean motion in such cases are analyzed. This work was supported by RFBR under Grant 96-02-19506.

DUSTY PLASMA SOLITONS IN THE IONOSPHERE

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Last time different dusty plasma structures in the space plasma are investigated.Typical examples of such structures are the spokes of the rings of the giant planets (Saturn, Jupiter),the condensations in the plasma cometary tail.In this report electrostatic spatially limited dusty plasma soliton structures in the low altitude ionospheric plasma are investigated.Spatial form,longitudinal and transverse sizes,dependence of the velocity on the soliton's amplitude is founded.The obtained results are used for the explanation of the bubbles in the low altitude ionosphere .

INTERACTION OF COHERENT WAVE WITH HELICAL TURBULENCE IN STRATIFIED SHEAR FLOW

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Interaction between large-scale internal wave and small-scale helical turbulence in plane Couette flow of fluid with statically stable uniform density gradient in gravitational field is studied basing on a set of equations for scalar and quasi-scalar wave fields and for helicity of turbulence. It is shown that helical turbulence provides coupling of scalar and quasi-scalar wave fields leading to exponential growth of wave amplitude, A, goverened by equation of the type $\dot{A} \sim S\alpha A$, where $\dot{A}$ denotes time derivative, S is shear of mean flow velocity, α is a parameter, proportional to helicity of small-scale turbulence. For this parameter algebraic equation $\alpha = \alpha_0 \left(1 + (A/A_0)^2\right)$ is derived in the case when small-scale turbulence is excited by external random helical force and linear stability parameter of mean flow is close to its critical value, dividing regimes with and without inviscid dissipation of linear disturbances in critical layer. This system of equation describes acceleration of wave growth due to its backward action on turbulence, i.e. wave-turbulent instability. This work was supported by RFBR under Grant 96-02-19506.

LABORATORY MODELING STABILITY OF THE LARGE-SCALE INTENSE BAROTROPIC ATMOSPHERIC POLAR ROSSBY VORTICES

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Laboratory modeling stability of the large-scale intense barotropic atmospheric polar Rossby vortices has been carried out. Vortices were created by the method of sources of mass (for anticyclones) and sinks of mass (for cyclones). The vortex sizes were greater or approximately equal to the Obukhov-Rossby radius. Water having a free surface was used as a working liquid. The experiments have shown that the vortices did not move from the paraboloid pole (where they were created). Dependence of the e-folding time (T) for the maximal linear rotation velocity of a vortex on the thickness (Ho) of the water layer has had the following peculiarities: (1) when Ho decreases from 7.5 cm to zero, the value of T decreases smoothly from 45 sec to To = 18 sec (for anticyclones) and from 38 sec to To = 12 sec for cyclones; (2) when Ho approaches zero, the value of T does not approach zero (as it takes place in the absence of the liquid free surface), but remains a rather large. These regularities are well explained by the theory of viscous Rossby vortex damping, with due account for the free surface.

ATMOSPHERIC AND LITOSPERIC RESPONSES ON LAUNCHES OF HEAVY SPACE VEHICLES, CONNECTED WITH CATASTROPHIC HAZARDS

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A heavy space vehicle launch is accompanied by formation of aerosol with participation of fuel combustion products. The aerosol is carried by wind on a large zone, descends, its particles influences on a troposphere lot as nuclei of condensation and crystallization of moisture. This causes an increase of cyclonical activity in the influence zone, in particular appearance frequency increase of strong and catastrophical precipitation and wind, turning of wind.
Coherent oscillations of atmospheric pressure over tectonic plates provokes seismic reactions in their borders, at that number affects on formation of strong earthquakes there. At the second half-wave of the oscillations grows seismisity in compressed borders (the main influence), at the first and party at the third half-wave it grows in strained them. Coherent oscillations in the environment provokes an infrastructure catastrophe frequency increase.
The heavy rockets launches further to switching on coherent trigger phenomena of realization of natural environment instability. The report will contain experimental, statistical characteristics of catastrophe-formative meteorological and seismic responses on launches of the heaviest rockets in Florida, meteorological and microseismical responses on launches of Russian rockets which belong to a middle their class, as well as some methods to decrease the negative consequences of space activity.

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Printed by Cambrian Printers, Aberystwyth, United Kingdom