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As we enter the final decade of the twentieth century, environmental protection has become a universal issue with world-wide support. Destruction of the stratospheric ozone-layer, global increase in carbon dioxide and other radiatively important trace gases, acid rain, urban smog, water pollution of various types, and improper disposal of toxic wastes have all been shown as pressing problems for the 1990's. Environmental studies have now bridged the realms of academic research and societal applications. Mathematical modelling and large-scale data collection and analysis lie at the core of all environmental studies. Examples of such issues are the protection of the ozone-layer, climate change, regional and urban pollution, toxic waste disposal and water pollution. While each of these environmental problems involves extremely complex interplay of many physical, chemical and even human interactions, mathematical analysis serves as the single unifying foundation. Because of the well-recognized highly intensive and perturbing impact of direct environmental experiments, computational models become the prevalent tool in identifying, assessing and resolving these problems. Further, the physical scale and complexity of these problems demand an immense quantity of data which depends upon statistical analysis both in its gathering and its interpretation. Unfortunately, scientists, mathematicians, and engineers immersed in developing and applying environmental models, computational methods, statistical techniques and computational hardware advance with separate and often discordant paces.

The Summer Program on Mathematical, Computational and Statistical Analyses in Environmental Studies was designed to provide a much needed interdisciplinary forum for joint exploration of recent advances in the formulation and application of (A) environmental models, (B) environmental data and data assimilation, (C) stochastic modeling and optimization, and (D) Global climate modeling. These four conceptual frameworks provided common themes among a broad spectrum of specific technical topics at this workshop. The program brough forth a mix of physical concepts and processes such as chemical kinetics, atmospheric dynamics, cloud physics and dynamics, flow in porous media, remote sensing, climate statistics, stochastic processes, parameter identification, model performance evaluation, aerosol physics and chemistry, and data sampling together with mathematical concepts in stiff differential systems, advective-diffusive-reactive PDE's, inverse scattering theory, time series analysis, particle dynamics, stochastic equations, optimal control and others.

STRUCTURE

(I) The program consisted of four parts:

A. Week 1 and 2: Environmental models

B. Week 2 and 3: Environmental data and assimiliation

C. Weeks 3 and 4: Stochastic modeling and optimization.

D. Week 4: Global climlate modeling.

The overlap in each segment of the program was intended to increase interaction among scientists and mathematicians working in specified areas.

A proceedings on "Environmental Studies" will be published as two volumes in the series IMA Volumes in Mathematics and its Applications (Springer-Verlag). Copies will be sent to the Air Force Office of Scientific Research when they are available.

"ENVIRONMENTAL STUDIES" PROCEEDINGS VOLUME CONTENTS

(papers received to date)

INSTITUTE FOR MATHEMATICS AND ITS APPLICATIONS

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Environmental Studies: Mathematical, Computational and Statistical Analyses

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"ENVIRONMENTAL STUDIES" PROCEEDINGS VOLUME
CONTENTS

(papers received to date)

INSTITUTE FOR MATHEMATICS AND ITS APPLICATIONS

University of Minnesota
514 Vincent Hall
206 Church Street S.E.
Minneapolis, Minnesota 55455
FAX (612) 626-7370 telephone (612) 624-6066
IMA schedules on Usenet: umn.math.dept e-mail: ima_staff@ima.umn.edu
TEXfiles of Newsletters and Updates via anonymous ftp: ima.umn.edu

IMA NEWSLETTER #194

July 1 - July 31, 1992

NEWS AND NOTES

IMA Summer Program

ENVIRONMENTAL STUDIES: MATHEMATICAL, COMPUTATIONAL, AND STATISTICAL ANALYSIS

July 6 - 31, 1992

ORGANIZERS

Mary Wheeler (Chair), Julius Chang, Michael Ghil
David McTigue, John Seinfeld, Paul Switzer

THE RATIONALE

Environmental protection has become an universal issue with world-wide support. Destruction of the stratospheric ozone-layer, global increase in carbon dioxide and other radiatively important trace gases, acid rain, urban smog, water pollution of various types, and improper disposal of toxic wastes have all been shown as pressing problems. Environmental studies have now bridged the realms of academic research and societal applications. Mathematical modeling and large-scale data collection and analysis lie at the core of all environmental studies. Unfortunately, scientists, mathematicians, and engineers immersed in developing and applying environmental models, computational methods, statistical techniques and computational hardware advance with separate and often discordant paces. The IMA Summer Program on Environmental Studies is designed to provide a much needed interdisciplinary forum for joint exploration of recent advances in this field.

PARTICIPATING INSTITUTIONS:Consiglio Nazionale delle Ricerche, Georgia Institute of Technology, Indiana University, Iowa State University, Kent State University, Michigan State University, Northern Illinois University, Northwestern University, Ohio State University, Pennsylvania State University, Purdue University, University of Chicago, University of Cincinnati, University of Houston, University of Illinois (Chicago), University of Illinois (Urbana), University of Iowa, University of Kentucky, University of Manitoba, University of Maryland, University of Michigan, University of Minnesota, University of Notre Dame, University of Pittsburgh, Wayne State University
PARTICIPATING CORPORATIONS:Bellcore, Cray Research, Eastman Kodak, Ford, General Motors, Hitachi, Honeywell, IBM, Kao, Motorola, Siemens, 3M, UNISYS

THE PROGRAM

A. Week 1 and 2 (July 6-17): Environmental models

B. Week 2 and 3 (July 13-24): Environmental data and assimilation

C. Weeks 3 and 4 (July 20-31): Stochastic modeling and optimization

D. Week 4 (July 27-31): Global climate modeling

The overlap in each segment of the program is intended to increase interaction among scientists and mathematicians working in specified areas. During the program there will be ten expository talks setting the physical and mathematical reference point for each type of environmental model or analysis, as well as the theoretical and applied research talks and informal discussions. Participants are encouraged to bring along material they might want to present.

The proceedings will be published as one or two volumes in the series IMA Volumes in Mathematics and its Applications (Springer-Verlag).

Most of the program talks will be held in Conference Hall 3-180 on the entry floor of the Electrical Engineering/Computer Science Building. This building is located on the corner of Washington Avenue and Union Street, a block from the IMA Main Office. The conference hall is on the Ethernet and has a projection system for display of computer output.

SCHEDULE FOR JULY 1 - JULY 31

(Weeks 1 and 2): ENVIRONMENTAL MODELS

The environment is a giant chemical reactor. Primary emitted pollutants are transported and transformed over spatial and temporal scales that range over many orders of magnitude. Environmental models that describe the transport and transformation of materials are based on laws of conservation of mass, momentum, and energy. These laws take the form of partial differential equations, frequently coupled and often nonlinear, that include advection, diffusion and chemical reaction processes. Particular difficulties involve the mathematical description of turbulent transport processes, phase changes, and large numbers of simultaneous chemical reactions.

In **toxic waste** sites further complications include geological descriptions of the porous media; that is, porosity, permeability, and fissures. Spatial variations in these physical heterogeneities lead to complicated flow patterns such as fingering and channeling. Since geological data is inexact and insufficient, the hydrodynamic equation or Darcy flow is frequently viewed as a stochastic partial differential equation.

Chemical reactions arise in flow in porous media in the modeling of sorption and degradation of substrates by indigenous microflora. The latter can be accelerated by introducing appropriate nutrients such as dissolved oxygen into the medium. In situ biodegradation is one of the most promising mitigation techniques for cleanup of toxic waste sites.

The mathematical issues in this part of the program include :

Stiff differential equations (chemical reaction)

Advection - diffusion PDE

Advection - diffusion - reaction PDE

Turbulence in Navier-Stokes Equations

Particle dynamics equations

Dynamical systems and chaos

Monday, July 6

Unless otherwise stated, the talks today are in Conference Hall EE/CS 3-180

9:00 am	**Registration and coffee**	Reception Room EE/CS 3-176
9:30 am	**Welcome and Orientation**	Conference Hall EE/CS 3-180
9:40 am	**Julius Chang** SUNY, Albany	Regional and atmospheric modeling

10:40 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Piotr K. Smolarkiewicz** NCAR	A class of semi-Lagrangian approximations for atmospheric fluids

Abstract: This paper discusses a class of finite difference approximations to the evolution equations of fluid dynamics. These approximations derive from elementary properties of differential forms. Values of a fluid variable at any two points of a space-time continuum are related through the integral of the space-time gradient of the variable along an arbitrary contour connecting these two points (Stokes' theorem). Noting that spatial and temporal components of the gradient are related through the fluid equations, and selecting the contour composed of a parcel trajectory and an appropriate residual, leads to the integral form of the fluid equations, which is particularly convenient for finite difference approximations. In these equations, the inertial and forcing terms are separated such that forces are integrated along a parcel trajectory (the Lagrangian aspect), whereas advection of the variable is evaluated along the residual contour (the Eulerian aspect). The virtue of this method is an extreme simplicity of the resulting solver; the entire model for a fluid may be essentially built upon a single one-dimensional Eulerian advection scheme while retaining the formal accuracy of its constant-coefficient limit. The Lagrangian aspect of the approach allows for large-Courant-number (> 1) computations in a broad spectrum of dynamic applications. Theoretical considerations are illustrated with examples of applications to selected classical problems of atmospheric fluid dynamics.

2:00 pm	**Jean M. Bahr**	On the choice between kinetics-based and local equilibrium models for reactive solute transport in groundwater

Abstract: The fate of dissolved contaminants in groundwater depends on both the nature of the groundwater flow field and any chemical reactions that can attenuate, retard or remobilize solutes. Chemical reactions can be incorporated into mathematical models of solute transport either as kinetically-based source/sink terms in equations that express a mass-balance for individual species or through equilibrium expressions in equations that express a mass-balance for a set of species constituting a component or "tenad". Kinetics-based formulations are theoretically valid for all conditions but may present numerical difficulties if characteristic reaction times are short relative to characteristic times for advective-dispersive transport. Even more significant constraints on this approach result from the fact that kinetics-based models require knowledge of the forms of rate laws and the magnitudes of associated rate constants. For reactions that can be considered reversible, models based on the approximation of local (or instantaneous) equilibrium have the advantage of requiring only knowledge of the thermodynamic equilibrium constants. However, if characteristic reaction times are long relative to characteristic transport times, local equilibrium-based models may be poor predictors of transport behavior. This presentation will review the effects of homogeneous and heterogeneous reactions on solute transport for conditions of local equilibrium and describe the deviations from equilibrium controlled transport behavior that may be observed if the local equilibrium approximation is not applicable. Data requirements for determining if a kinetics-based model is required will be discussed as a function of reaction class, source function, temporal and spatial scales of the problem, and modeling objectives.

4:00 pm	**Vincent Hall 502** (The IMA Lounge)	IMA Tea (and more!)

Tuesday, July 7

Unless otherwise stated, the talks today are in Conference Hall EE/CS 3-180

9:30 am	Leslie Smith University of British Columbia	Contaminant transport in fractured geologic media: Modeling approaches

Abstract: From a hydrologic perspective, a geologic unit that contains fractures is highly heterogeneous. Flow paths are controlled by the fracture geometry. They may be erratic and highly localized. In contrast, granular porous media, while also heterogeneous, often exhibit smoothly varying flow fields that are amenable to treatment as equivalent continua. The complex patterns of flow in fractured media suggest that the well-developed and long used techniques for modeling fluid flow and solute transport in porous media may not be

successful when applied to fractured rock. The purpose of this lecture is three fold: (1) to summarize recent views on the development of conceptual models of fluid flow and transport in fractured geologic media, (2) to discuss and assess the state of the art in numerical simulation, and (3) to outline research needs to improve our capabilities when using models either for scenario analysis or predictive simulation.

10:30 am	Coffee Break	Reception Room EE/CS 3-176

11:00 am	Gour-Tsyh Yeh Penn State University	On diagonalization of coupled hydrologic transport and geochemical reaction equations

Abstract: Two basic ingredients present in modeling the transport of reactive multi-components: the transport is described by a set of advection-dispersio-reactive partial differential equations (PDEs) based on the principle of balance; the chemical reactions, under the assumptions of local equilibrium, are described by a set of highly nonlinear algebraic equations (AEs) base on the principles of mole balance and mass action. Currently there are basically three approaches to modeling the coupled hydrologic transport and geochemical equilibrium reactions: (1) the mixed differential and algebraic equations (DAE) approach (2) the direct substitution approach (DSA) and (3) the sequential iteration approach (SIA). For the DAE approach, a subset of equations is solved for the chosen primary dependent variables (PDVs) and the remaining of the equations are used to compute for the secondary dependent variables (SDVs). For DSA, the chemical equilibrium reaction equations are substituted into the hydrologic transport equation to result in a set of nonlinear partial differential equations which are subsequently solved simultaneously for the chosen PDVs. For SIA, the procedure consists of iterating between sequentially solving the hydrologic transport equations for the chosen PDVs and solving geochemical equilibrium equations for the SDVs. No matter which approach is taken, the choice of PDVs is of a primary importance, which would ultimately determine if a model is of any practicality. Because the number of simultaneous PDEs and AEs are large, the most important consideration in choosing PDEs is: (1) it should decouple the system as much as possible, (2) it should be able to deal with the complete suite of geochemical reactions, and (3) it should yield nonlinear source/sink terms as small as possible. This paper presents a discussion on the choice of characteristics variables as PDVs based on the diagonalization of the simultaneous nonlinear PDEs resulting from the DSA approach. Examples will be given to demonstrate that using characteristic variables as PDVs, one could reduce the complete set of the simultaneous PDEs and AEs to a much more manageable form, to which efficient numerical schemes could be applied for solving practical problems.

Joint work with Hwai-Ping Cheng.

2:00 pm	Michael A. Celia Princeton University	On the use of pore-scale models for multiphase flow in porous media

Abstract: Pore-scale models of fluid-fluid displacement in porous solids may be used to model certain aspects of multiphase flow in porous media. These models can provide capillary pressure vs. saturation and relative permeability vs. saturation constitutive relationships at the continuum-porous-medium scale. Both two-phase and three-phase systems may be modeled. This presentation will review basic concepts of pore-scale models and present both experimental and computational results to demonstrate model applications.

3:00 pm	Coffee Break	Reception Room EE/CS 3-176

3:30 pm	Mankin Mak University of Illinois, Urbana	Hadley circulation and atmospheric variability

Abstract. "Hadley Circulation" is a major component of the global atmospheric circulation. It is traditionally defined as the longitudinally and annually averaged component of the circulation in the tropical atmosphere. In terms of the flow on a latitude-height cross-section, it has the structure of a closed cell in each hemisphere, extending from the surface to the tropopause and from the equator to about 30 degrees latitude. There is an associated zonal wind structure with a weak surface easterly flow and a progressively stronger westerly aloft north of about 10 degrees latitude.

The first mathematical analysis models the Hadley circulation as a forced flow in a zonally symmetric model subject to a representative radiative forcing symmetric about the equator. The nonlinear systems turns out to be important even in this simplest possible model in determining the structure of the response. This problem has been investigated both as a boundary value problem and an initial value problem.

The second mathematical analysis addresses the seasonally and longitudinally averaged circulation which is under the influence of a steady forcing located asymmetrically with respect to the equator. The asymmetry with respect to the equator in the seasonal Hadley circulation turns out to be much stronger than the asymmetry in the forcing. Specifically, the winter Hadley cell is much stronger and extensive than that of the summer Hadley cell. The steady state model response can become unstable under representative conditions.

The third mathematical analysis investigates the time dependent character of the Hadley circulation which arises partly from the annual cycle of the forcing and partly from the instability of the forced flow. For a large dissipation, the model Hadley circulation has an oscillation alternately dominated by the winter cells in the two hemispheres with a brief transition season. Even for a moderate dissipation, the winter Hadley circulation becomes unstable and higher frequency fluctuations emerge. Such fluctuations have periods of about 10 to 20 days. They occur first at the edge of the winter Hadley cell in the summer hemisphere. It is found that these unstable modes of motion propagate equatorward and downward. The whole system fluctuates throughout a year in the form of a complex limit cycle with several time scales. For a weak dissipation, the high frequency fluctuations have the characteristics of chaos which appear as additional fluctuations modulated by a background annual cycle of the broad aspect of the Hadley cell.

A limited data analysis has been made to identify some of the basic characteristics of the observed Hadley circulation. The fluctuations of the actual Hadley circulation is believed to have great impacts upon the global climate fluctuations including the intraseasonal and interannual atmospheric variability. The full impacts of the fluctuations of the Hadley circulation, however, will not be understood until their feedback effects with the oceans are included in a more comprehensive model study.

I will discuss these four analyses in this talk with some details. The various mathematical issues encountered in this study will be elaborated in the discussion.

Wednesday, July 8

Unless otherwise stated, the talks today are in Conference Hall EE/CS 3-180

9:30 am	**David Chock** Ford Motor Company	Physics, chemistry and modeling of air pollution
10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Roger A. Pielke** Colorado State University	Regional and mesoscale atmospheric modeling

Abstract: There has been a revolutionary improvement in our capability to model regional and mesoscale atmospheric flows over the last several years. One advancement has been the development of telescoping nested grid models which permit large- and small-scale meteorological processes to be simulated simultaneously. At the Conference, and in our paper in the IMA Volume in Mathematics and its Application, we will present selected model results using this capability.

The second development involves the development of high performance computer workstations which have computational power of a substantial fraction of mainframe supercomputers yet at a fraction of the cost. In addition, effective and economical visualization software and large data storage peripheral devices have been introduced. The computational capabilities of these workstations will be discussed at the Conference and in our paper.

Joint work with W.R. Cotton, C.J. Trenback, R.L. Walko and W.A. Lyons.

2:00 pm	Contributed talks and Demonstrations

2:00 pm	**Christine Shoemaker** Cornell University	Video tape on optimal groundwater remediation (for people gone on Friday)
2:15 pm	**Robert Chatfield** NASA	An overview of commonly used solution techniques for the chemical kinetic equations in air chemistry
2:30 pm	**Rachid Ababou** SRI	Effective models for flow in heterogeneous porous media
3:00 pm	**Sanford Sillman** University of Michigan	On representing localized chemistry in global atmospheric models – resolving the dilemma of grid size

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Thursday, July 9

Unless otherwise stated, the talks today are in Conference Hall EE/CS 3-180

9:30 am	**Mario J. Martinez** Sandia National Laboratories	Some modeling issues in nuclear-waste isolation

Abstract: The need to isolate nuclear waste from the natural and human environment raises numerous mathematical modeling issues. Many of these are common to the entire spectrum of hazardous materials, but some issues are relatively unique to the area of radioactive waste. We emphasize in this paper some of the singular aspects of hydrological model analyses needed to design, and to establish the acceptable performance of, nuclear waste repositories. We illustrate these modeling challenges with specific examples from our own experience in providing model development and analysis in support of several United States radioactive waste isolation programs.

Proposed disposal schemes and candidate sites invariably confront the modeler with materials and conditions for which there is little experience. There has been no impetus historically to study transport processing in geological media that *minimize* flow and dispersion. The analyst must often put aside the assumptions made for conventional groundwater flow, identify new or unorthodox transport mechanisms, and develop a mathematical representation for these processes. Some considerations of the thermomechanical response of water-saturated clay are discussed as an example. In this case, there is a strongly coupled interaction of heat transfer, pore water pressurization and flow, and creep deformation of the porous skeleton.

A second, striking aspect of nuclear waste disposal is that it demands consideration of very long time scales, for beyond traditional modeling experience. Radionuclide decay times can be very long, and federal regulations governing waste isolation accordingly impose standards on scales of 10^3, 10^4, and 10^5 years. This puts an unprecedented importance on modeling; decisions must be based on predictions that, in many cases, cannot be tested empirically over the appropriate time scales. The long-term behavior of rock salt and the associated seepage of brine are discussed as an example of this type of modeling challenge. On time scales of, say, hours to months, the salt can exhibit the response characteristic of classical, Darcy flow. On longer time scales, however, there can be indications of phenomena such as dilatation and permeability growth due to stress relief and shearing, development of discrete fractures, and multiphase flow due to imhibition of air and exsolution of gases from the brine.

Finally, we discuss the prevalence of heterogeneity in geological materials. Although present in all hydrogeological systems, variability of material properties is a particularly important issue in nuclear waste disposal. Fractures are heterogeneities that arise often in geological media. In water-saturated media, the fractures provide high-conductivity pathways for transport of contaminant-laden liquids. The same is true for gases in unsaturated media. However, for liquids, fractures may play the role of either conduits or barriers to flow, depending on the degree of water saturation in the unfractured matrix, and the local flux intensity. Understanding the role of fractures in fluid transport is important to both pre- and post-emplacement performance assessments.

Joint work with David McTigue.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176

11:00 am	**William G. Gray** University of Notre Dame	On the importance of interfaces in multi-phase flow theory

Abstract: The common occurrence of water infiltration into an unsaturated porous medium has proven to be a difficult problem to describe from both conceptual and theoretical perspectives. The conceptual hurdles have led researchers to allow absolute water pressure to take on negative values and to define capillary pressure as a hysteretic function equal to the air phase pressure (atmospheric) minus the water phase pressure (e.g. -15 atmospheres at the wilting point). Theoretical approaches to the infiltration problem consist primarily of the introduction of relative permeability into Darcy's law for single phase flow.

As an alternative, a systematic theoretical framework will be outlined which provides macroscale equations of mass, momentum, and energy conservation for multiphase flow and for the interfaces between the phases. Constitutive equations needed to close the system are subjected to the constraint imposed by the second law of thermodynamics. Examination of the infiltration problem within this framework leads to macroscale thermodynamic relations including a thermodynamic expression for the capillary pressure and insight into the macroscale origins of hysteresis.

2:00 pm	**John Robert Philip** CSIRO Canberra	Mathematical physics of infiltration on flat and sloping topography

Abstract: We review the modern mathematical physical analysis of water movement in unsaturated soils, which is central to understanding of the terrestrial segment of the hydrologic cycle: the relevant flow equation is a strongly nonlinear Fokker-Planck (convection-diffusion) equation. The theory of infiltration (the penetration into a soil mass of water made available at its surface) is described. Solutions are developed for infiltration into horizontal soil surfaces, and for infiltration and downslope flow on hillslope topographies. Both ponded and constant-rainfall infiltration are treated. The emphasis is on quasi-analytic and analytic solutions. Fully nonlinear solutions are developed, together with linearized solutions of certain problems. The nonlinear solutions involve either usefully convergent series or traveling waves. The linearizations make use of integral matching procedures and product solutions.

3:00 pm	**Coffee Break**	Reception Room EE/CS 3-176
3:30 pm		Contributed talks and Demonstrations

25 minute talks/demonstrations with 5 minutes for questions and comments.

3:30 pm	**John Knight** CSIRO	Unsaturated soil water flow around underground obstacles
4:00 pm	**Mark Curran** Sandia National Labs	Massively parallel multigrid-based mixed finite element approximations to groundwater flow
4:30 pm	**Mark Curran** Sandia National Labs	A domain decomposition approach to local grid refinement in finite-element collocation (applies to advection-diffusion equation)
5:00 pm	**Vincent Hall Atrium**	**Environmental Studies BBQ Picnic**

Grilled hamburgers and Wisconsin bratwurst, potato salad, fresh vegetables, watermelon and soft drinks. Cost is $10 (waived for visitors receiving local expenses). Reservation required by July 6 at 4:00 pm. (Math Lounge first floor if rain.)

Friday, July 10

Unless otherwise stated, the talks today are in Conference Hall EE/CS 3-180

9:30 am	**Christine Shoemaker** Cornell University	Optimal control algorithms for groundwater remediation

Abstract: This talk will discuss the development and application of large scale optimal control algorithms. The primary application discussed will be the remediation of contaminated groundwater, which can cost hundreds of millions of dollars at a single site. This presentation will describe the use of the optimal control algorithm Differential Dynamic Programming to determine the most cost-effective location of pumping wells and time-varying pumping rates. A finite element model of contaminant transport is coupled to the Differential Dynamic Programming (DDP) algorithm. Numerical results will be presented for several examples involving hundreds of state variables and pumping over periods of up to 15 years and 60 management periods. Large savings in cost are obtained for example cases by using the optimal control approach over earlier simulation or nonlinear programming approaches. The advantages of alternative computational approaches will be discussed including the use of management periods, quasi-Newton approximations, and parallel processing methods. Numerical results will also be presented that indicate that DDP requires many fewer iterations than the nonlinear programming method for hypothetical optimal control problems.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Clarence A. Miller** Rice University	Interfacial phenomena in ground water cleanup

Abstract: Leaks and spills of gasoline, chlorinated solvents, and other organic liquids with low solubility in water are known to have contaminated numerous aquifers and are believed to threaten many others. With two liquid phases plus air present in the portion of the aquifer above the water table, it is evident that interfacial phenomena are important for contaminant flow and transport. Their importance is greater still if surfactants are employed, as has been suggested for some situations.

A general discussion of how interfacial phenomena influence both the original contamination process and possible remediation methods will be given. Some recent results from the author's group and from the literature will be included where pertinent.

2:00 pm		Contributed talks and Demonstrations

25 minute talks/demonstrations with 5 minutes for questions and comments.

2:00 pm	**Julius Chang** SUNY Albany	.5 minute video on Acid Rain Modeling
2:05 pm	**Zhangxin Chen** University of Minnesota	Modeling of compositional flow in fractured reservoirs
2:30 pm	**Heinz Hass** Universitat Zu Koln	Interaction of chemistry and dynamics as modelled in a regional chemistry-transport model (EURAD)
3:00 pm	**Jon Pleim** EPA	A simple non-local closure scheme for vertical mixing in the convective boundary layer
3:30 pm	**John C. Bruch, Jr.** UC Santa Barbara	A parallel, adaptive mesh finite element iterative scheme for flow in porous media

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(Weeks 1 and 2): ENVIRONMENTAL MODELS
(Weeks 2 and 3): ENVIRONMENTAL DATA AND DATA ASSIMILATION

Ultimately, progress in environmental research depends on acquiring and properly utilizing observational information. Data may come from land-based monitoring stations or from aircraft and satellites. Data may be episodic or periodically collected and will involve various levels of temporal and spatial averaging. Data are needed for initialization of models, parameter estimation, characterization of variability and uncertainty, pattern recognition, model evaluation, compliance monitoring, and trend detection.

Inverse Scattering Problem in Remote Sensing. Global data in the atmosphere can best be obtained through remote sensing from a satellite. These then require the solution of a class of inverse scattering problems to obtain the physical variable of interest. Due to the throughput of the instruments, very efficient and robust algorithms are needed.

Parameter Identification. When parameters in a basic model are unknown and cannot be determined from separate laboratory experiments, the parameters can be determined such that the output of the model optimally matches a set of field data. As such, the parameter identification problem is an inverse problem in which the forward problem is governed by a set of PDEs. Many important questions exist in parameter identification concerning the selection of data to be used and the numerical techniques for addressing the generally ill-posed inverse problem that results.

Model Performance Evaluation. Because models cannot hope to capture all the complexity of natural systems, it becomes important to assess their shortcomings in light of direct observations. Performance evaluation consists of establishing the appropriate spatial and temporal resolution of models.

Design for Data Collection. Important design questions arise both for data collection related to environmental monitoring for compliance and trend detection as well as for purposes related to the evaluation of models. Efficient siting of monitoring locations and appropriate choices of monitoring frequency are important for the utilization of limited resources. The design problems are necessarily difficult because of the complexity of patterns of spatial and temporal variability.

Epidemiology. Assessing health effects of environment pollution is both an important and difficult problem because of widespread exposure of human populations to pollutants, the difficulty of ascertaining pollutant doses, and the difficulty of final pollutant-sensitive responses. Careful modelling is needed both in the attribution of dosage and in the articulation of dose-response functions. The presence of errors both in the dosage and the response presents important challenges for environmental epidemiology.

Time Series Analysis. Environmental and meteorological measurements often come in the form of time series. Both time domain and frequency domain time series analysis can shed light on the important empirical structures. Such analyses are important for detection of trends. One important research area concerns the combination of many short time series in a regional monitoring network for the purpose of separating common trend components from site-specific components.

The mathematical issues in this part of the program include:
Inverse problems
Time Series
Design for data
Inverse Scattering
Parameter identification
Statistical procedures for model performance evaluation

Monday, July 13

Unless otherwise stated, the talks today are in Conference Hall EE/CS 3-180

9:30 am	**Welcome and Orientation**	Conference Hall EE/CS 3-180
9:40 am	**Mary Wheeler** Rice University	Modeling of biodegradation of hydrocarbons in groundwater
10:40 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**E.A. Sudicky** University of Waterloo	Contaminant migration in complex-structured geologic media: From local-scale processes to field-scale prediction

Abstract: Contaminant transport in natural geological formations at the field-scale is strongly affected by three-dimensional spatial variations in the hydraulic and chemical-sorption properties of the host medium. The hydraulic conductivity of subsurface strata, which controls the rate of contaminant advection, can, for example, vary by many orders of magnitude. The presence of fractures in clays and consolidated rocks and

discontinuities such as root holes or macropores in near-surface soils represent another form of heterogeneity. In the case of reactive contaminants, sorption parameters describing their affinity to adhere to the solid phase comprising the geological materials can also vary markedly form point to point, and the sorption process itself can range from the instantaneous and reversible type to kinetically controlled ones. Although advanced three-dimensional numerical models have been developed to assess the fate of contaminants in groundwater, the natural heterogeneity of geologic materials combined with complex local-scale advection, dispersion and reaction processes represents a major obstacle to performing reliable predictions of plume evaluation and to the design of effective detection, monitoring and aquifer remediation strategies. This has brought about, in recent years, the development of stochastic theories that account for spatial heterogeneity by using the geostatistical properties of the geological formation to estimate the values of effective parameters describing the large-scale advective and dispersive behaviour of contaminants transported by groundwater and the uncertainty associated with field-scale predictions. Only recently, however, have stochastic theories been developed that describe reactive solute transport. These theories attempt to estimate the large-scale sorption and dispersive properties of reactive contaminants based on the spatial variability of the flow field, the spatial variability of the parameters describing the sorption occurring between the solute and the geologic material, and possible correlations between the hydraulic and the sorption parameters,

Field experiments performed in sandy aquifers involving organic and inorganic tracers have demonstrated enhanced dispersion of reactive contaminants relative to nonreactive ones, and a temporal growth of the effective retardation factor describing the bulk sorption of a reactive solute. While it has been suggested that these effects may be caused by kinetically-controlled rather than equilibrium sorption reactions, as well as processes such as intraparticle diffusion, recent theoretical developments based on stochastic-analytic theory indicate that jointly heterogeneous hydraulic and sorption parameter fields can account for the enhanced dispersion of a reactive solute and also for the apparent time dependence of the bulk retardation factor.

Our purpose here is to examine the sensitivity of the reactive-solute transport process at the field-scale to the type and degree of correlation between the heterogeneous hydraulic and sorption parameter fields and the form of competing models commonly used to describe the local-scale sorption process. The influence of factors leading to transport nonidealities such as intraparticle diffusion and the presence of macropores and fractures will also be addressed. The general approach taken involves a series of exceedingly detailed three-dimensional simulations of reactive and nonreactive solute transport in synthetic heterogeneous aquifer materials, as well as comparison of the numerical results to field observations and theoretical predictions based on stochastic-analytic theory. In the case of a reactive solute a newly developed Direct Fourier Transform random field generator is used to co-generate pairs of three-dimensional random fields of hydraulic conductivity and sorption parameters. The fields in each pair are self-correlated in space and they are cross-correlated to each other. Differences between the evolution of nonreactive and reactive contaminant plumes at the field-scale are highlighted and issues related to prediction uncertainty due to imperfect knowledge of the properties of hydrogeological systems are discussed.

Joint work with M. Th. van Genuchten.

2:00 pm	**Clint Dawson** Rice University	Effects of lag and maximum growth in contaminant transport and biodegradation modeling

Abstract: We will discuss a mathematical and numerical model for microbial biodegradation of contaminants in groundwater. Based on laboratory experiments, a new system of equations describing microbial reaction kinetics has been developed. This model includes the effects of lag and maximum growth. To validate the model, laboratory and numerical experiments have been performed. A time-splitting modified method of characteristics has been used to numerically approximate the resulting system of partial differential equations. Comparison between numerical and laboratory experiments will be given.

Joint work with Brian Wood and J.E. Szecsody, Pacific Northwest Laboratory.

4:00 pm	**Vincent Hall 502** (The IMA Lounge)	IMA Tea (and more!)

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Tuesday, July 14

Unless otherwise stated, the talks today are in Conference Hall EE/CS 3-180

9:30 am	**E.A. Sudicky** University of Waterloo	Containment transport in irregularly-fractured porous media: Pump-and-treat remediation and implications of matrix diffusion
10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Tom W. Fogwell** International Technology Corp.	Multigrid methods for modeling multiphase fluid flow in porous media

Abstract: An implementation of multigrid applied to some typical discretizations of the partial differential equations governing the flow of more than one phase in porous media is presented. An overview of the equations and special problems in the use of multigrid methods for these kinds of problems with large jump discontinuities in the coefficients are given. Some details of the specific multigrid case methods, some applications to test problems, and a discussion of parallel implementation are presented

2:00 pm	**Linda M. Abriola** University of Michigan	Some challenges in modeling nonaqueous phase organic contaminant transport in the subsurface

Abstract: After a brief overview of the subject of NAPL contamination, this presentation focuses on two aspects of the modeling of these multiphase flows in porous media: mass balance and interphase mass transfer.

The first topic relates to the mass conservation properties of the algorithms commonly employed to model organic infiltration events. Poor mass balance performance for two- and three-phase flow simulators has been reported by a number of investigators In this presentation, alternative finite element and finite difference, pressure- and pressure/saturation-based, formulations are compared for their mass balance accuracy under severly nonlinear conditions. Non-traditional finite element approximations for the capacity coefficients are introduced. It is demonstrated that good mass balance accuracy can be obtained with all formulations, as long as coefficients and initial conditions are properly treated.

In the second part of the presentation, recent research pertaining to the modeling of entrapped organic phase dissolution is discussed. A series of laboratory experiments was conducted to explore this dissolution process in a range of sandy aquifer materials. Results from these experiments are summarized and the data are employed to develop conceptual models for dissolution. Two alternative models are considered, a lumped domain approach and a model which treats mass transfer coefficients and area independently. The developed models are incorporated into a finite element transport simulator. Model simulations of transient dissolution scenarios are compared with laboratory data. Predictive capabilities and model limitations are discu ed

Joint work with Klaus Rathfelder, Susan Powers, Timothy Dekker, and Walter J. Weber, Jr.

3:00 pm	**Coffee Break**	Reception Room EE/CS 3-176

Numerical Analysis Seminar

3:30 pm	**San-Yih Lin** National Cheng Kung University	Numerical methods for aerodynamic problems

The SEMINAR meets in Vincent Hall 570.

Wednesday, July 15

Unless otherwise stated, the talks today are in Conference Hall EE/CS 3-180

9:30 am	**Naihua Duan** Rand Corporation	Statistical issues in air pollution exposure assessment

Abstract: Air pollution exposure assessment has gone through a number of revolutionary changes during the last two decades. With new technological innovations, it has become feasible to measure individuals' exposures directly using miniaturized monitors or docimeters. For some pollutants such as carbon monoxide (CO), it is possible to measure exposures in real time with fine time resolution on the order of seconds. For some pollutants such as volatile organic compounds (VOC's), it is only possible to measure integrated exposures with time resolutions on the order of days or hours.

The new technologies have been applied to several large scale field studies, such as U.S. EPA's Total Exposure Assessment Methodology (TEAM) studies. Each of those studies enrolled a random sample of human subjects, equipped them with monitoring devices, and measured their individual exposures. Each subject also filled out a diary to record their activities during the monitoring period, and additional questionnaires on their background characteristics and physical environment.

A number of challenging statistical issues have come out of those new field studies. I will address two of those issues. First, I will discuss how to deconvolute the exposure distribution based on integrated exposure measurements, to estimate the nature of the sources of the exposures, by combining the exposure measurements with the diary data on the potential sources the subject was in contact with during the monitoring period. Second, I will discuss how to evaluate the nature of long-term average exposures using short-term exposure measurements, so as to make inference about the distribution of health risk for cumulative effects such as carcinogenicity.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Ulrich Hornung** SCHI	Models for transport through fractured porous media derived by homogenization theory

Abstract: One of the major topics in mathematical modeling of environmental processes is the simulation of transport (diffusion, convection, adsorption) and reaction of chemical substances through soils. This problem leads to coupled systems of nonlinear parabolic equations. It is a fact - well established in soil physics and soil chemistry - that the usual approach leads to poor predictions of the processes observed in the field. In the paper we are going to present a "double porosity" model which can be derived by homogenization. The notion of "two-scale convergence" will be described and numerical examples will be shown.

2:00 pm		Contributed talks and Demonstrations

25 minute talks/demonstrations with 5 minutes for questions and comments.

2:00 pm	**J. Brannan & J. Haselow** Clemson U. & Westinghouse	Compound random field models of multiple scale hydraulic conductivity
2:30 pm	**W.J. Maier & R.S. Maier** University of Minnesota	Modeling and parameter estimation of microbial growth and transport
3:00 pm	**Coffee Break**	Reception Room EE/CS 3-176
3:30 pm		Contributed talks and Demonstrations

25 minute talks/demonstrations with 5 minutes for questions and comments.

3:30 pm	**Bill Rayens** University of Kentucky	Dependence structures for constrained multivariate data
4:00 pm	**Joe Wang** Lawrence Berkeley National Lab	Problems in statistical analyses and fractal modeling associated with unsaturated flow in fractured rocks

Thursday, July 16

Unless otherwise stated, the talks today are in Conference Hall EE/CS 3-180

9:30 am	**James Glimm** SUNY, Stony Brook	A theory of macrodispersion for the scale up problem

Abstract: Dispersion is the result, observable on large length scales, of events which are random on small length scales. When the length scale on which the randomness operates is not small, relative to the observations, then classical dispersion theory fails. The scale up problem refers to situations in which randomness occurs on all length scales, and for which classical dispersion theory necessarily fails. The purpose of this article is to present anomalous, or non Fickian, theories of dispersion, which do not assume a scale separation between the randomness and the observed consequences.

Porous media flow properties are heterogeneous on all length scales. The geological variation on length scales below the observational length scale can be regarded as unknown and unknowable, and thus as a random variable.

We develop a systematic theory relating scaling behavior of the geological heterogeneity to scaling behavior of the fluid dispersivity. Three qualitatively distinct regimes (Fickian, anomalous and nonrenormalizable) are found. The theory gives consistent answers within several distinct analytic approximations, and for numerical simulation of the equations of porous media flow.

Comparison to field data is made. The use of Kriging to generate constrained ensembles for conditional simulation is discussed.

Joint work with W. Brent Lindquist, Felipe Pereira and Qiang Zhang.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**John H. Cushman** Purdue University	Nonlocal transport in microporous systems

Abstract: The physics of flow and transport in natural geologic formations and soils involves numerous scales of motion. This presentation concerns itself only with the smallest scale characteristic of clays and shales, though much of the theory presented is applicable over a continuum of scales.

Numerical statistical mechanical experiments suggest that fluids in the smallest of pores can take on elastic, viscoelastic or viscous characteristics depending on the size of the pore and the relative structure of the pore walls. In the spirit of modern continuum physics we exploit the entropy inequality to obtain the formal structure of a linear constitutive theory for such fluids. The constitutive theory is used to outline a statistical mechanical theory which in turn is used in computational experiments. Generalized hydrodynamics is used in the development of a nonlocal diffusion model which in turn is used to characterize the relaxation of the fluid.

2:00 pm	**Todd Arbogast** Rice University	A characteristics-mixed method for advection dominated transport problems

Abstract: We define a new method for approximating the solution to an advection dominated transport problem. The method is locally conservative. It treats the advection part of the equation with a characteristic traceback. The diffusion and spatial discretization is handled by a mixed finite element method. Convergence estimates are derived. Some numerical results are presented in 1, 2, and 3 space dimensions.

3:00 pm	Coffee Break	Reception Room EE/CS 3-176
3:30 pm		Contributed talks and Demonstrations

25 minute talks/demonstrations with 5 minutes for questions and comments.

3:30 pm	**Walter F. Jones** Clemson University	A moving finite element solution of the unsaturated flow equation

Joint work with Chris Cox, Clemson University.

4:00 pm	**H.O. Pfannkuch** University of Minnesota	Mass transfer and source function at an oil-water spill interface in a groundwater environment

Joint work with Lifeng Guo, University of Minnesota.

4:30 pm	**Mark Curran** Sandia National Labs	In situ permeable flow sensor (A device for measuring groundwater flow velocity)

The talk concerns a groundwater velocity probe to get 3-D velocity field, which is being tested at Savannah River.

5:00 pm	**Vincent Hall 570 & 502**	**Environmental Studies Pizza Party**

Pizza, salad and soft drinks will be served.

Friday, July 17

Unless otherwise stated, the talks today are in Conference Hall EE/CS 3-180

9:30 am	**Lynn W. Gelhar** MIT	Field-scale contaminant transport in aquifers: Stochastic theory and field applications

Abstract: Natural subsurface heterogeneity plays an essential role in the behavior of contaminants in aquifers. Theories of transport in heterogeneous aquifers adopt a random field description of the small-scale variations of hydraulic properties. The flow and transport processes are then described by stochastic differential equations with random coefficients. These stochastic differential equations have been solved using several different linearized approximations, all of which presume relatively small variations and produce essentially the same results. Here the Eulerian-based spectral approach emphasized because it provides simple physical insight and is easily extended to cases of reactive, multicomponent, multiphase, and coupled transport. Based on comparisons with field experiments and high-resolution numerical numerical simulations for nonreactive solutes under saturated conditions, the linearized stochastic theories are found to be surprisingly robust. Extensions of the theory to nonideal transport situations (unsaturated flow, viscosity/density coupling, biodegradation) are explored. The influence of the scale of the plume relative to the scale of heterogeneity is discussed in the context of new theoretical results which are based on two-particle transport theory. Essentially the macrodispersivities needed to characterize mixing and dilution in a single real aquifer are dependent on the scale of heterogeneity and the size of the plume; dilution is smaller for smaller plumes.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Richard Ewing** University of Wyoming	Eulerian-Lagrangian localized adjoint methods for reactive-diffusive transport of contaminants in groundwater

Abstract: In this paper, we present Eulerian-Lagrangian Localized Adjoint Methods (ELLAM) to solve convection-diffusion-reaction equations governing contaminant transport in groundwater flowing through an absorbing porous medium. These ELLAM schemes are extensions of those presented by Celia, Russell, Herrera, and Ewing in 1990. They are developed to accurately treat various types of boundary conditions in a mass-conservative formulation. By treating the advection directly, these methods greatly reduce truncation errors arising from the discretizations. Numerical results are presented and discussed.

Joint work with Hong Wang.

Industrial Postdocs Seminar

The seminar will meet from 1:00 - 3:30 pm today. The format of the seminar is:

1) Presentation of projects and problems from industry (3M, Honeywell, Alliant Techsystems and Siemens) on which the industrial postdocs are working.

2) Informal suggestions and discussion among the participants.

The seminar is directed by Avner Friedman and Walter Littman. Those wishing to participate should contact Avner.

The SEMINAR meets in Vincent Hall 570

(Weeks 2 and 3): ENVIRONMENTAL DATA AND DATA ASSIMILATION
(Weeks 3 and 4): STOCHASTIC MODELING AND OPTIMIZATION

While deterministic models for fluid flow and contaminant transport in ideal porous media are well established, geological materials present difficult modeling challenges. One of the greatest of these is to account for the extreme heterogeneity of material properties inherent in soils and rocks. For example, permeability can vary by many orders of magnitude over even small length scales. Furthermore, it is not just the magnitude of this variability, but its spatial correlation structure as well, that controls the overall response of the system.

A substantial research effort is being made currently to develop mathematical descriptions of such stochastic systems. A primary goal has been to identify appropriate "effective" properties that can be estimated from statistics of locally-measured properties. In addition to variable material properties, natural systems of interest also exhibit stochastic boundary conditions (e.g., surface infiltration due to rainfall) and initial conditions (e.g., the distribution of a contaminant in a chemical waste landfill). The mathematical tools for treating such problems are in an early stage of development.

A related issue is that of scaling. For example, the transport properties of a soil or rock may be characterized in the laboratory at a scale of a few centimeters or in a field test that samples over perhaps several meters. However, the desired model may be needed to simulate processes over several kilometers. A well-known example is the observation that dispersion of a tracer in a porous medium increases with the scale of the test. Again, the mathematical tools to address this question are in an early stage of development. Similar issues relative to stochastic processes and material properties arise across the entire spectrum of environmental modeling, whether in the atmosphere or in the ocean.

Cross-fertilization from other fields, such as turbulence modeling, in which issues of stochastic processes, scaling, and effective properties have long been studied, offers great promise.

Spatial Stochastic Processes. Unexplained spatial and temporal fluctuations in pollutant concentration can be modeled using stochastic processes which try to capture the statistical properties of the residual field. Recent work in this area includes non-stationary models, multivariable processes, and models with long-range dependence.

In porous media, physical and chemical heterogeneities are frequently modeled stochastically by carrying out many realizations in which the correlation length or coefficient of variation is held fixed; distributions generated by fractals are also employed.

Optimization. In porous media, wells are drilled for both production and injection. The pumping of substrates and the injection of fluids to accelerate displacement or biodegradation of substrates are effective but costly remediation techniques. Determination of optimal well placement and flow rates is an optimal control problem. To date only "model" problems have been investigated.

Sensitivity Analysis. Environmental models are characterized by significant uncertainties that are frequently manifested by parameters in the basic conservation equations that are not accurately known. Understanding the uncertainty in model predictions that results from uncertainties in parameters is important in model application. Sensitivity analysis involves systematically varying the parameters of a model and computing the model output in a manner that allows one to assess which parameters are most influential and how the overall uncertainty in model predictions can be attributed to individual parameter uncertainties. Because large models typically have many parameters, the problem of designing an efficient sensitivity analysis becomes important.

The mathematical issues of this part of the program include:
Sensitivity analysis
Spatial Stochastic processes
Scaling
Heterogeneity (physical and chemical)

Design for data
Epidemiology (Empirical model) **Monday, July 20**

Unless otherwise stated, the talks today are in Conference Hall EE/CS 3-180

9:30 am	**Grace Wahba** University of Wisconsin	Adaptive tuning of numerical weather prediction models, and related data assimilation questions

Abstract: We discuss some problems in combining heterogenous, scattered direct and indirect data from many sources, to estimate some physical quantities of interest, with special application to the estimation of initial conditions for numerical weather prediction models, given forecast, observations, and a priori physical information. We will discuss several methods for optimizing smoothing, weighting and tuning parameters for data assimilation that can be implemented in the context of extremely large ($10^5 - 10^6$) data sets.

10:40 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**George F. Pinder** University of Vermont	Dense non-aqueous phase liquid flow and transport simulation in the subsurface using collocation and domain decomposition

Abstract: Dense non-aqueous phase liquid contamination of the subsurface is a very serious environmental problem. The simulation of this problem requires the solution of a coupled set of four non-linear partial-differential equations in at least two space dimensions. To accommodate problems of reasonable size, a collocation approach can be used to approximate the governing equations. The resulting approximating equations can be solved very efficiently using a domain decomposition approach in combination with a parallel processing computer. The results of the analysis can be presented using animated graphics and a video projector. Problems of practical significance have been addressed.

Joint work with Joseph F. Guarnaccia.

2:00 pm	**David E. Dougherty** University of Vermont	Computing and modeling for groundwater remediation design

Abstract: The economic impacts of groundwater remediation—clean-up—are quite large and well-known. It is increasingly evident that relatively small investments in groundwater modeling, computer simulation, and optimization can reap significant savings without a reduction in environmental goals. It is also becoming clear that misuse or misinterpretation of uncertainties, such as arise in subsurface characterization, can have substantial negative effects, whether caused by over-design, under-design, or misallocation of culpability. In light of these observations, we have been pursuing a program of research to assist in improving the design of remediation systems by focussing on issues in computation and modeling. The paper reviews key questions and some (proposed) answers for practical applications using classical and novel methods. The strategy that we are developing relies on an applications-oriented, "keep your eyes on the prize" point of view. On the other hand, the methods we use to implement the strategy are neither "quick and dirty" nor always intuitively obvious. The discussion touches on a broad spectrum of topics, including quasi-potential flow, advection-diffusion-reaction simulation, subsurface characterization techniques, optimization, reliable design, numerical methods, and parallel computation.

Joint work with Andrew F. B. Tompson, Donna M. Rizzo and Margaret J. Eppstein.

4:00 pm	**Vincent Hall 502** (The IMA Lounge)	IMA Tea (and more!)

Tuesday, July 21

Unless otherwise stated, the talks today are in Conference Hall EE/CS 3-180

9:30 am	**Peter Guttorp** University of Washington	Stochastic precipitation models

Abstract. We review some different approaches to modeling precipitation stochastically. Such models are important for hydrologic applications, but can also, in some cases, be used for meteorological forecasting and

assessment of general circulation models. While stochastic precipitation models have been around at least since the 1840's, the last two decades have seen an increased development of models based (more or less) on the physical processes involved in precipitation. There are interesting questions of scale and measurement that pertain to these modeling efforts.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**C.J. van Duijn** Delft University of Technology	Analytical and numerical aspects of reactive solute transport in porous media. I

Abstract: In two lectures we consider some fundamental aspects of reactive contaminant transport in porous media. We discuss: (i) equilibrium and non-equilibrium multiple-site adsorption, (ii) travelling wave solutions, (iii) uniqueness, stability and existence of solutions, (iv) large time behaviour of solutions and (iv) finite-element approximation algorithmic aspects and error-estimates.

2:00 pm	**P. Knabner** IAAS, Berlin	Analytical and numerical aspects of reactive solute transport in porous media. II

Abstract: In two lectures we consider some fundamental aspects of reactive contaminant transport in porous media. We discuss: (i) equilibrium and non-equilibrium multiple-site adsorption, (ii) travelling wave solutions, (iii) uniqueness, stability and existence of solutions, (iv) large time behaviour of solutions and (iv) finite-element approximation algorithmic aspects and error-estimates.

Wednesday, July 22

Unless otherwise stated, the talks today are in Conference Hall EE/CS 3-180

9:30 am	**Akio Arakawa** UCLA	Global atmospheric modeling as a component of modeling the climate system
10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Steven K. Seilkop** Analytical Sciences Inc.	Methods for addressing spatial scale differences in comparisons of regional atmospheric model predictions with field monitoring data

Abstract: The evaluation of regional scale atmospheric models is often based on comparisons with land-based monitoring data. In performing these comparisons, there is an *a priori* expectation that the model will not replicate the data perfectly since the data are subject to measurement error and atmospheric phenomena that occur at finer spatial scales than the model is designed to replicate. To interpret comparisons of model predictions against data, it is therefore important to characterize and quantify data variability at spatial scales commensurate with model predictions. This presentation provides a characterization of the spatial/temporal variability structure of air concentration and predipitation chemistry data, and demonstrates the use of these data in evaluating the performance of a regional scale atmospheric model.

Contributed Talks

2-2:30 pm	**George F. Pinder** University of Vermont	The use of computer models in groundwater contaminant litigation: The Woburn trial from the eyes of an expert witness

Joint work with Stuart Stothoff, David Ahlfeld and Christopher Hull.

2:30 pm	**Praveen Kumar** University of Minnesota	A multicomponent decomposition of spatial rainfall for studying its scaling behavior

Abstract: Issues of scaling characteristics in spatial rainfall have attracted increasing attention over the last decade. Several models based on simple/multi scaling and multifractal ideas have been put forth and

parameter estimation techniques developed for the hypothesized models. Simulations based on these models have realistic resemblence to "generic rainfall fields". In this research we analyze rainfall data for scaling characteristics without an a priori assumed model. We look at the behavior of rainfall fluctuations obtained at several scales, via orthogonal wavelet transform of the data, to infer the precise nature of scaling exhibited by spatial rainfall. The essential idea behind the analysis is to segregate large scale (long wavelength) features from small scale features and study them independently of each other. The hypothesis is set forward that rainfall might exhibit scaling in small scale fluctuations, if at all, and at large scale this behavior will break down to accomodate the effects of external factors affecting the particular rain producing mechanism. The validity of this hypothesis is examined. In addition we define and estimate parameters that characterize the spatial dependence of the rainfall fluctuations and we use these parameters, estimated for several frames (in time), to relate to and identify the evolutionary nature of rainfall. These parameters and the type of scaling show significant variation from one rainfall field to another.

Joint work with Efi Foufoula-Georgiou.

3:30-4 pm	**Mark S. Handcock** New York University	Incorporating the model uncertainty into spatial predictions

Abstract: We consider a modeling approacn for spatially distributed data. We are concerned with aspects of statistical inference for Gaussian random fields when the ultimate objective is to predict the value of the random field at unobserved locations. However the exact statistical model is seldom known before hand and is usually estimated from the very same data relative to which the predictions are made. Our objective is to assess the effect of the fact that the model is estimated, rather than known, on the prediction and the associated prediction uncertainty. We describe a method for achieving this objective. We conclude that in many practical situations this uncertainty has a large impact on the estimated uncertainty of the prediction and a lesser effect on the predicted value itself.

We, in essence, conside the best linear unbiased prediction procedure based on the model within a Bayesian framework. Particular attention is paid to the treatment of parameters in the covariance structure and their effect on the quality, both real and perceived, of the prediction.

These ideas are implemented for the temperature and precipitation over the region in the northern United States based on the stations in the United States historical climatological network reported in Quinlan, Karl & Williams (1990).

Thursday, July 23

Unless otherwise stated, the talks today are in Conference Hall EE/CS 3-180

Topic: Data assimilation (atmosphere and oceans)

9:30 am	**Michael Ghil** UCLA	Sequential estimation applied to atmospheric and oceanic data assimilation
10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Olivier Talagrand** CNRS	Variational assimilation of atmospheric observations

Abstract: Sequential assimilation, and its extension under the form of Kalman filtering, described in the presentation of M. Ghil, are based on successive introductions of observations into a time integration of the assimilating model. If it's not followed by a form of backward integration, sequential assimilation allows the information contained in the observations to be carried only into the future, but not into the past.

Variational assimilation, on the contrary, tends to globally adjust a model solution to all the observations available over the assimilation period. More precisely, variational assimilation minimizes a scalar function which, for any model solution, measures the "distance" between that solution and the available observations. If the model equations are imposed as a constraint to be exactly verified, the state of the model at the beginning of the assimilation period can be taken as *control variable*, with respect to which the minimization is performed. Variational assimilation is made practically possible by the use of the *adjoint* of the assimilating model, through which the gradient of the distance function with respect tot he initial state can be computed at an acceptable cost.

In the case of linear equations, variational assimilation can be shown to lead to the same final estimate at the end of the assimilation period as Kalman filtering. Sequential and variational assimilations are therefore not fundamentally different methods, but rather different algorithms for producing the same result.

Variational assimilation has been implemented in the last years, at the experimental level, on atmospheric and oceanic models of progressively increasing complexity. As concerns atmospheric models, the most recent experiments (J.N. Thépaut, Doctoral thesis, Université Paris 6, Paris, June 1992) have been performed with "primitive equation" models similar to those used in operational numerical weather prediction. These experiments show that variational assimilation is capable of efficiently minimizing the distance function, even with state dimension on the order of $10^4 - 10^5$. However, the minimizing solution is meteorologically realistic only if the distance function contains one or several appropriate penalty terms intended at eliminating spurious high-frequency gravity waves. Comparative experiments with sequential assimilation schemes similar to operational schemes show that variational assimilation is capable of using the information contained in the model equations in a much more consistent and efficient manner. This is obtained at a higher, but non prohibitive, numerical cost.

The variational method therefore seems to be very promising for assimilation. A number of problems nevertheless remain. It is not clear yet what impact "threshold processes", such as for instance convection, can have on variational assimilation, it would be useful to make the numerical algorithms more efficient, and it is not known how variational assimilation will behave when the assimilation period becomes long enough for the chaotic character of the flow to become significant. One particular side advantage of variational assimilation is that the adjoint model which must be developed can then be used for the solution of a wide variety of sensitivity and identification problems.

2:00 pm	**Robert N. Miller** Oregon State University	Optimal data assimilation in oceanography – Practice and theory
3:00 pm	**Coffee Break**	Reception Room EE/CS 3-176
3:30 pm		Contributed talks and Demonstrations
3:30 pm	**H.J. Thiébaux** US Dept. of Commerce	Global objective analysis – Some problems and solutions
4:00 pm	**Gary W. Oehlert** University of Minnesota	Regional trends in sulfate wet deposition

Abstract: We propose a multiple time series model for data from a network of monitoring stations which have both temporal and spatial correlation. The model includes a separate mean and trend for each monitoring station and obtains spatial estimates of mean and trend by smoothing the observed values over a rectangular grid using a discrete smoothing prior. Smoothing parameters and covariance estimates can be chosen subjectively or selected using indirect generalized cross validation. The gridded values and their standard errors can be used for several purposes, including inference on regional means or trends and improving monitoring networks via station rearrangement.

4:30 pm	**John Petkau** University of British Columbia	Air pollution and human health: A study based on data from Prince George, British Columbia

Abstract: The purpose of this study was to examine the relationships between ambient levels of air pollution and human health in the community of Prince George, British Columbia. The available data consist of daily counts of hospital admissions and emergency room visits for respiratory illnesses and the daily values of various air pollution parameters from April 1, 1984 to March 31, 1986. This talk will describe the methodology used to carry out the study and the results obtained. No such associations were apparent for the hospital admissions series. A clear association emerged between emergency room visits and total

reduced sulphur compounds, although the corresponding effect is relatively small. A similar relationship, corresponding to a substantially larger effect, is only suggested for total suspended particulates.

5:45 pm	**Buffet Dinner**	Campus Club, 4th floor, Coffman Union

Reservations required. Wine and cheese will be available starting at 5:45. We go through the dinner line at 6:30.

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Friday, July 24

Unless otherwise stated, the talks today are in Conference Hall EE/CS 3-180

9:30 am		Contributed talk
9:30 am	**I. M. Navon** Florida State University	Variational 4-dimensional data assimilation methods and efficient large scale optimization

Abstract: The topic of variational 4-D data assimilation methods using adjoint optimal control methods will be introduced and illustrated by case studies derived from recent research work carried out by the author and several of his collaborators.

These case studies involve experience with 4-D variational data assimilation using an adiabatic version of the N.M.C. spectral model, the impact of incomplete observations and control of gravity waves in variational data assimilation (VDA), parameter estimation applied to obtain optimal nudging coefficients, second order adjoint analysis and its various applications and finally some research work now in progress on the adjoint sensitivity analysis for blocking events using a two-layer simplified climate model.

VDA with threshold physical processes will be also briefly surveyed.

A condensed overview of large-scale optimization methods in meteorology is then presented with the aim to briefly survey recent developments in the application of large-scale nonlinear programming and optimal control methods in the field and illustrated by case studies.

We will also discuss the most adequate reliable and robust unconstrained minimization methods for large-scale problems in meteorology and oceanography based on our cummulated experience.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am		Contributed talks and Demonstrations
11-11:45 am	**Kenneth R. Driessel** Idaho State University/IMA	On the equilibrium equations of poro-elasticity

Abstract: In this report, I shall derive the equations that govern the equilibrium behavior of a porous, elastic material. I shall use the two-space method of homogenization. (These equations were originally derived by M. A. Biot in a different way.) I intend this derivation to be an elementary introduction to the use of homogenization to derive effective medium equations. In particular, I shall assume that on a microscopic scale (e.g., 'grain size' in the case of a porous rock) the material consists of an elastic solid and fluid-filled pores. I 'average' the equations which govern the microscopic equilibrium behavior to obtain equations on a larger 'macroscopic' scale (e.g., the size of a core sample in the case of a porous rock). I obtain equations that are similar to the equations of elasticity but which have an additional term involving the pressure of the fluid in the pores.

I shall also discuss some experimental data which test the theory. In particular, I assume that the material is uniform (i.e., homogeneous) and isotropic on the macroscopic scale. I solve the resulting equations for a cylinder. I show how to use this solution to calculate the parameters that govern the behavior of the material. Finally, I determine these parameters from some experimental data.

11:45-Noon	**R.W.R. Darling** University of South Florida	Hurricane risk assessment

Abstract: Suppose you are the operator of a nuclear power plant on the coast of Florida, and the regulators tell you that you must study the risks associated with extreme hurricanes with a 'return period' of 10,000 years. However the tropical cyclone database only goes back to the last 100 years. This talk is a non-technical introduction to tropical cyclones and the data about them, and presents a statistical model of the Atlantic tropical cyclones (reference: R.W.R. Darling, Journal of Climate, 1991)

(Weeks 3 and 4): STOCHASTIC MODELING AND OPTIMIZATION
(Week 4): GLOBAL CLIMATE MODELING

Global Climate dynamics provides a meeting and testing ground for the two areas of recent inquiry: 1) the theory and modeling of complex biogeophysical systems, and 2) the theory and applications of nonlinear dynamical systems. During this week, the lectures and participants will examine various aspects of modeling separate subsystems of the global environment, the problems of coupling between subsystems characterized by different spatial and temporal scales, and issues raised by the analysis and prediction of large nonlinear systems.

The mathematical issues of this week include:
Bifurcation theory
Ergodic theory of dynamical systems
Estimation and filtering
Homogenization
Parallel algorithms
Stochastic processes

Monday, July 27

Unless otherwise stated, the talks today are in Conference Hall EE/CS 3-180

9:30 am	**George C. Tiao** University of Chicago	Comparison of observed ozone and temperature trends in the lower stratosphere

Abstract: In the recent published WMO Ozone Assessment Report (WMO, 1989), it is reported that there is a significant negative ozone trend in the lower stratosphere and upper troposphere from 1970 through 1986. In this talk we examine the relationship of this trend in ozone to that of temperature in the same altitude region utilizing a 62 station set of rawinsonde data, and compare the results to the changes in temperature determined from a radiative equilibrium model calculation. The calculated and observed trends in lower stratospheric temperature indicate substantive agreement in shape and magnitude of the vertical profiles.

10:40 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**David J. Thomson** AT&T Bell Laboratories	Estimating the time-derivative of a spectrum: Detecting changes in climate variability

Abstract: One of the expected components of the greenhouse effect is an increase in climate variability, for example both severe droughts and floods are expected to increase, but detection is difficult because the data is highly autocorrelated. Moreover, because of the various periodic and quasi-periodic components in the system, these effects may be most obvious as modulation products at frequencies away from the origin and so appear as changes in the spectrum. Here we examine the problems of detecting non-stationarity in short data samples using a variant of quadratic-inverse theory (Phil. Trans. R. Soc. Lond. A **332**, pp 539-97, 1990.) We decompose the covariance matrix of the eigencoefficients used in multiple-window spectrum estimation methods (Proc.IEEE **70**, pp 1055-96, 1982) into a series of known basis matrices with scalar coefficients. For a given bandwidth and sample size, we describe simultaneous orthogonal expansions for both the power(time) function and for the eigencoefficient covariance matrix. The limiting power basis functions are eigenfunctions of a narrow band sinc^2 kernel while the corresponding basis matrices are trace-orthogonal so that the observable non-stationary is described by a series of quadratic forms.

2:00 pm	**James C. McWilliams** NCAR	Asp:cts of eddy transports in oceanic climate variability

Abstract: A broad survey will be made of the essential roles that small-scale, transient motions (eddies) play in the evolution of large-scale oceanic fields of material properties such as temperature, salinity, carbon-cycle constituents, and other tracers (climate). Particular attention will be given to two topics: (1) vertical transports by 3D turbulence in the planetary boundary layers at the air-sea interface and the solid earth and (2) the quasi-adiabatic, isopycnally oriented transports by mesoscale eddies. For each of these new parameterizations will be presented and assessed.

3:00 pm	**Jacob Bear** Israel Institute of Technology	Modeling transport phenomena in porous media

Abstract: The paper reviews the continuum approach to modelling the transport of mass, momentum and energy, of phases and of their components in a porous medium domain. The review begins with the definition of a porous medium, making use of the concept of a Representative Elementary Volume (REV) as a tool for overcoming the effect of the microscopic heterogeneity resulting from the presence of a solid matrix and a void space. The microscopic and macroscopic levels of description are defined. By averaging the description of a transport phenomenon at the microscopic level over an REV, using certain 'averaging rules', the macroscopic or continuum description of the same phenomenon is obtained. This methodology is first introduced in general terms for any extensive quantity, and then demonstrated for the transport of mass, momentum and energy.

In the process of deriving the macroscopic models, expressions are presented also for the advective, dispersive and diffusive fluxes of extensive quantities that appear in them, in terms of averaged, measurable values of state variables.

'4:00 pm	**Vincent Hall 502** (The IMA Lounge)	IMA Tea (and more!)

Tuesday, July 28

The talks today are in Vincent Hall 570

9:30 am	**Joseph J. Tribbia** NCAR	Forced zonal flow over topography and the 30-60 day oscillation in atmospheric angular momentum

Abstract: A model governed by the equivalent-barotropic potential vorticity equation on the sphere is used to investigate the 30-60 day oscillation in the extratropical atmosphere. The model is forced by a zonally-symmetric stress and is subject to dissipation by surface friction. Discretization by spherical harmonics is truncated triangularly at degree 21 (T21), to yield 461 real modes, used also for the representation of the Earth's topography. A bifurcation study is carried out for this model in phase-parameter space, by the pseudo-arclength continuation method.

The model exhibits multiple unstable equilibria, with oscillatory instabilities having periods of 15-20 days, 30-60 days and 180 days, in a realistic range of the forcing. While most of the model activity occurs in the Northern Hemisphere, the behavior of equatorial critical lines is dissipative, rather than reflective, preventing false resonances. A 4000-day model run, performed at the most interesting and realistic parameter values, is analyzed in detail.

Singular spectrum analysis of this run's total atmospheric angular momentum (AAM) indicates a substantial 30-60 day oscillation. Composite flow fields keyed to the AAM show this oscillation to be associated with strong fluctuations in pressure difference across the Rockies and Himalayas. The oscillation arises from non-linear interaction between unstable modes of the equilibrium closet to the run's climatology. A comparison band occurring in a general circulation model and an atmospheric data set reveals intriguing similarities.

Joint work with Michael Ghil.

10:30 am	Coffee Break	Reception Room EE/CS 3-176

11:00 am	**M. Ghil** UCLA	Infraseasonal oscillations in the global atmosphere: Observations, theory and GCM experiments

This talk will include an 8 minute video clip.

2:00 pm	**Fei-Fei Jin** UCLA	Tropical ocean-atmosphere interaction
3:00 pm	**Coffee Break**	Reception Room EE/CS 3-176
3:30 pm		Contributed talks and Demonstrations

Wednesday, July 29

The morning talks are in Vincent Hall 570

9:30 am	**Paul Switzer** Stanford University	Assessing the statistical uncertainty of regional trend estimates

Abstract: Regional trend estimates derived from monitoring data will carry more or less uncertainty depending on the length of the monitoring period, the geographic configuration of the monitoring stations and the evolution of this configuration over time, the availability of covariate information, the spatial heterogeneity of the region, and the inter-annual and the inter-seasonal variability and autocorrelation structure. Illustrations of trend estimation of regionally averaged surface temperature will exhibit the statistical modeling tools needed to develop uncertainty assessments. These illustrations show how statistical uncertainty is affected by natural climate variability and the imperfections of the observation record.

10:30 am	**Coffee Break**	Vincent Hall 502
11:00 am	**P.D. Jones** University of East Anglia	Global surface temperature changes since 1854

Abstract: Analysis of land and marine temperatures shows that the world has warmed by about 0.5° C since the middle of the nineteenth century. Considerable care is necessary in dealing with the basic land-based station and marine data to ensure that various nonclimatic factors such as changing observational practices and urbanization influences from town and city growth are not present in the analyzed data. The warming since the last century has not been distributed evenly in space or throughout the year. Maps of temperature anomalies for a number of periods during the twentieth century will be shown, including the 1980's (the warmest decade in global terms) and 1990 (the warmest year).

Special Demonstration

1:30 pm	**P.D. Jones** University of East Anglia	Demonstration of World Climate Disc and STUGE

Dr. Jones will demonstrate World Climate Disc (global climatic change data on CD-ROM). The Disc combines data from thousands of meteorological stations with a digital map of the world and specially developed retrieval and presentation software.

He will also demonstrate the computer model STUGE (Sealevel and Temperature Under the Greenhouse Effect). This model takes user defined scenarios for greenhouse gases and generates temperatures and sea levels from the present to the year 2100.

The DEMONSTRATION will be held in Conference Hall EE/CS 3-180

2:30 pm	Coffee Break	Reception Room EE/CS 3-176

3:00 pm	**James J. Hack** NCAR	Directions in atmospheric general circulation modeling

Abstract: One of the more important longstanding problems in the modeling of larg· scale atmospheric motions, particularly with respect to climate, is how to accurately include the various components of the hydrological cycle, into the governing meteorological equations. Many aspects of the hydrologic cycle are now, in principle, readily derivable from satellite remote sensing instruments. These measurements provide an exceptional opportunity to better verify general circulation model results. This talk will focus on the importance of the large-scale water vapor field to the Earth's climate system, and the need to hold atmospheric general circulation models to higher performance standards through the use of remote sensing measurements of atmospheric water. We will also examine the role of alternative computing technologies for facilitating global climate modeling and verification.

The TALK will be held in Conference Hall EE/CS 3-180

CURRENT IMA PARTICIPANTS

LONG-TERM PARTICIPANTS IN RESIDENCE

Bennett, Karin R.	IMA	
Chen, Xinfu	University of Pittsburgh	MAY 4 - AUG 20
Dobson, David C.	IMA	
Donato, Jerry	self-employed/industrial researcher	JUN 10 91 - AUG 28
Driessel Kenneth R.	Idaho State Univ.	AUG 29 91 - AUG 1
Elliott, Frank W., Jr.	IMA	
Fatemi, Emad	IMA	
Fehribach, Joseph	IMA	
Friedman, Avner	IMA	
Hoffend, Thomas R. Jr.	IMA	
Hu, Bei	University of Notre Dame	MAY 18 - AUG 15
Kimura, Tsuyoshi	KAO Corporation	MAR 17 - MAR 1 93
Kirkland, Stephen	IMA	
Kloucek, Petr	EPF Lausanne	JAN 21 - JUL 31
Lewkowicz, Izchak	IMA	
Littman, Walter	University of Minnesota	
Mathias, Roy	IMA	
Miller, Willard	IMA	
Mukherjee, S.	Mahatma Gandhi Degree College	SEP 4 90 - AUG 31
Nagy, James G.	IMA	
Shader, Bryan	IMA	
So, Wasin	IMA	
Velazquez, Juan J.L.	Universidad Complutense	SEP 8 91 -JUL 5
Xu, Yongzhi	IMA	

SUMMER PROGRAM PARTICIPANTS IN RESIDENCE

Ababou, Rachid	SRI	JUL 5 - JUL 12
Abriola, Linda	University of Michigan	JUL 12 - JUL 17
Adams, John	Rand Corporation	JUL 20 - JUL 31
Arakawa, Akio	UCLA	JUL 21 - JUL 23
Arbogast, Todd	Rice University	JUL 6 - JUL 24
Bahr, Jean M.	University of Wisconsin	JUL 5 - JUL 10
Bear, Jacob	Israel Institute of Technology	JUL 26 - JUL 29
Binkowski, Francis	U.S. Environmental Protection A.	JUL 6 - JUL 10
Blaskovich, David	Cray Research Inc.	JUL 6 - JUL 31

Brahm, Matt	University of Minnesota	JUL 6 - JUL 31
Brannan, James R.	Clemson University	JUL 5 - JUL 22
Bruch, John	UC Santa Barbara	JUL 4 - JUL 11
Burk, Thomas	University of Minnesota	JUL 6 - JUL 31
Celia, Michael	Princeton University	JUL 4 - JUL 10
Chang, Julius	SUNY, Albany	JUL 5 - JUL 12
Chatfield, Robert	NASA	JUL 5 - JUL 9
Chen, Zhangxin	University of Minnesota	JUL 1 - JUL 31
Chock, David	Ford Motor Company	JUL 6 - JUL 12
Conquest, Loveday	University of Washington	JUL 19 - JUL 31
Cooke, Kenneth	Pomona College	JUL 5 - JUL 8
Cowsar, Lawrence	Rice University	JUL 6 - JUL 18
Cox, Chris	Clemson University	JUL 5 - JUL 17
Cressie, Noel	Iowa State University	JUL 20 - JUL 23
Curran, Mark C.	Sandia National Labs	JUL 6 - JUL 17
Cushman, John H.	Purdue University	JUL 11 - JUL 18
Darling, R.W.R.	University of South Florida	JUL 19 - JUL 26
Dawson, C.	Rice University	JUL 12 - JUL 25
Dobbert, Daniel J.	Metro. Mosquito Control Dist.	JUL 6 - JUL 31
Dougherty, David	University of Vermont	JUL 8 - JUL 24
Duan, Naihua	Rand Corporation	JUL 12 - JUL 17
Embid, Pedro	University of New Mexico	JUL 5 - JUL 15
Engel, Mark	SUNY Buffalo	JUL 5 - JUL 18
Ewing, Richard E.	University of Wyoming	JUL 15 - JUL 17
Fogwell, Thomas W.	International Technology	JUL 5 - JUL 20
Gelhar, Lynn W.	MIT	JUL 12 - JUL 17
Ghil, Michael	UCLA	JUL 21 - JUL 29
Gianni, Roberto	Universita di Firenz	JUL 5 - JUL 18
Glimm, James	SUNY, Stony Brook	JUL 12 - JUL 17
Glinsman, Diane	Cray Research	JUL 6 - JUL 31
Golala - A - Kadir	Yarmouk University - Jordan	JUL 6 - AUG 31
Gray, William G.	University of Notre Dame	JUL 4 - JUL 9
Gualtierotti, A.	University of Lausanne	JUL 5 - AUG 1
Gunst, Richard	Southern Methodist University	JUL 26 - JUL 31
Gupta, Satish C.	University of Minnesota	JUL 6 - JUL 31
Guttorp, Peter M.	University of Washington	JUL 19 - JUL 31
Hack, James	NCAR	JUL 28 - JUL 29
Handcock, Mark	New York University	JUL 18 - JUL 25
Hansen, D. Alan	EPRI	JUL 5 - JUL 10
Hardy, Tim	University of Northern Iowa	JUN 1 - AUG 1
Hass, Heinz	Universitat Zu Koln - Germany	JUL 5 - JUL 14
Hilhorst, Danielle	Universite de Paris - Sud	JUL 5 - JUL 17
Horn, Mary Ann	University of Virginia	JUL 1 - JUL 31
Horntrop, David	Princeton University	JUL 5 - JUL 18
Hornung, Ulrich	SCHI	JUL 6 - JUL 17
Jernigan, Robert	The American University	JUL 18 - JUL 24
Jin, Fei-Fei	UCLA	JUL 27 - JUL 29
Jones, Phil	University of East Anglia	JUL 25 - JUL 31
Jones, Walter	Clemson University	JUL 5 - JUL 17
Kalnins, Ernie	Univ. of Waikato, New Zealand	JUL 4 - JUL 10
Kamel, Merzik	University of New Brunswick	JUL 5 - JUL 18
Kawabe, Midori	University of Tokyo	JUL 5 - JUL 25
King, Scott	University of Minnesota	JUL 6 - JUL 31

Kirkland, Stephen	IMA	JUL 1 - JUL 31
Klink, Kathy	University of Minnesota	JUL 6 - JUL 31
Knabner, Peter	Universitat Augsburg	JUL 5 - JUL 25
Knight, John Howard	CSIRO	JUL 5 - JUL 11
Lau, Ka-Sing	University of Pittsburgh	JUL 25 - JUL 30
Lin, San-Yih	National Cheng Kung University	JUL 6 - JUL 31
Mak, Mankin	University of Illinois at Urbana	JUL 6 - JUL 9
Mannucci, Paola	University di Firenz	JUL 5 - JUL 18
Martinez, Mario	Sandia National Labs	JUL 5 - JUL 10
Mays, Tony	Cray Research	JUL 6 - JUL 31
McTigue, David	Sandia National Labs	JUL 6 - JUL 8
McWilliams, James	NCAR	JUL 26 - JUL 31
Meiring, Wendy	University of Washington	JUL 12 - JUL 25
Miller, Clarence	Rice University	JUL 6 - JUL 10
Miller, Robert N.	Oregon State University	JUL 22 - JUL 31
Minhas, Faqir		JUL 5 - AUG 1
Moon, Robert J.	Cincinnati Technical College	JUL 5 - JUL 22
Morris, Brian C.	Occidental College	JUL 5 - AUG 1
Moss, Bill	Clemson University	JUL 5 - JUL 22
Myers, Donald E.	University of Arizona	JUL 19 - JUL 24
Navon, Michael	Florida State University	JUL 20 - JUL 24
Neerchal, Nagaraj	University of Maryland	JUL 18 - AUG 3
Oehlert, Gary	University of Minnesota	JUL 20 - JUL 24
Patil, Ganapati	Penn State University	JUL 16 - JUL 17
Peletier, L.A.	University of Leiden	JUL 6 - JUL 31
Petkau, John	University of British Columbia	JUL 19 - JUL 25
Pfannkuch, Hans-Olaf	University of Minnesota	JUL 6 - JUL 31
Philip, John Robert	CSIRO	JUL 5 - JUL 11
Pielke, Roger	Colorado State University	JUL 7 - JUL 12
Pinder, George	University of Vermont	JUL 19 - JUL 22
Pleim, Jonathan	U.S. Environmental Protection A.	JUL 5 - JUL 12
Rathbun, Stephen	University of Georgia	JUL 18 - JUL 26
Rayens, William S.	University of Kentucky	JUL 12 - JUL 24
Roberson, Kyle	Battelle Pacific Northwest Lab	JUL 12 - JUL 18
Sampson, Carolyn	University of Minnesota	JUL 6 - JUL 31
Sarkis, Marcus	Courant Institute	JUL 5 - JUL 11
Seilkop, Steve	Analytical Sciences Inc.	JUL 19 - JUL 24
Shoemaker, Christine	Cornell University	JUL 6 - JUL 10
Sillman, Sanford	University of Michigan	JUL 6 - JUL 10
Smith, Leslie	University of British Columbia	JUL 5 - JUL 9
Smolarkiewicz, Piotr	NCAR	JUL 5 - JUL 10
Stech, Harlan	University of Minnesota, Duluth	JUL 1 - JUL 3
Stein, Michael	University of Chicago	JUL 20 - JUL 24
Strakos, Zdenek	Cxzch. Acad. of Sciences	JUL 1 - JUL 7
Sudicky, E.	University of Waterloo	JUL 13 - JUL 17
Switzer, Paul	Stanford University	JUL 27 - JUL 29
Talagrand, Olivier	Lab. de Meteorologie Dynamique	JUL 20 - JUL 25
Thiebaux,Jean	US Dept. of Commerce	JUL 18 - JUL 24
Thomson, David	AT&T Bell Laboratories	JUL 27 - JUL 31
Tiao, George	University of Chicago	JUL 26 - JUL 28
Tribbia, Joseph J.	NCAR	JUL 26 - JUL 31
Trunnell, David	Xavier University	JUL 5 - JUL 23
Umeda, Tom	Bay Area Air Quality Man. Dist.	JUL 12 - JUL 25

Van Der Zee, Sjoerd	Wageningen Agricultural U.	JUL 13 - JUL 24
Van Duijn, Hans	Delft University of Technology	JUL 5 - AUG 1
Ver Hoef, Jay M.	Alaska Dept. of Fish and Game	JUL 19 - JUL 24
Vorwerk, Karin	Clemson University	JUL 5 - JUL 11
Wahba, Grace	University of Wisconsin	JUL 19 - JUL 24
Wang, Joseph	Lawrence Berkeley National Lab	JUL 12 - JUL 19
Wang, Wei - Chyung	SUNY, Albany	JUL 27 - JUL 31
Wheeler, Mary	Rice University	JUL 5 - JUL 17
Yeh, George	Penn State University	JUL 5 - JUL 12
Zhang, Bingyu	University of Cincinnati	JUL 1 - JUL 31
Zou, Xiaole	Florida State University	JUL 20 - JUL 24