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ABSTRACT (Maximum 200 words)

Meeting has been structured to encouraged collaboration between biological and physical oceanographers, numerical modelers, mathematicians and meteorologists who use Lagranian measurements, both in-situ and simulated, to understand and model ocean and coastal dynamics. The following main topics were discussed: Observations and biological applications; Theory of dispersion/transport/mixing; A day of interactions via a group social activity; Lagranian instruments and data analysis techniques; and Assimilation of Lagranian data and predictability of trajectories.

14. SUBJECT TERMS

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Lagrangian Analysis and Predictability of Coastal and Ocean Dynamics

2000 LAPCOD Meeting
Ischia, Italy
October 2-6, 2000

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Outline

LAPCOD Meeting Agenda

Dear Participant,

welcome to Ischia!

A few words to remind you that this meeting has been structured to encourage collaborations between biological and physical oceanographers, numerical modelers, mathematicians and meteorologists who use Lagrangian measurements, both in-situ and simulated, to understand and model ocean and coastal dynamics. In the next five days we will devote our time to discuss the following main topics:

Mon:	A	Observations and biological applications.
Tue:	B	Theory of dispersion/transport/mixing.
(Wed:		A day of interactions via a group social activity)
Thu:	C	Lagrangian instruments and data analysis techniques.
Fri:	D	Assimilation of Lagrangian data and predictability of trajectories.

Monday's session will focus on estimates of first and second-order statistics of velocity, plankton, tracer and optical properties of the ocean and coastal regime from Lagrangian measurement. We have encouraged contributions that contain maps of mean circulation, transport, MKE, and EKE, Lagrangian spectra and covariance functions, variance ellipses, principal component analysis, diffusivity estimates, and estimates of Lagrangian time scales that can be used as benchmarks for modeling studies and for parameterizing turbulence.

Tuesday's session will focus on theoretical and numerical models of particle dispersion, turbulent mixing and transport. Contributions on nonlinear particle dynamics, chaotic advection, tracer dispersion, turbulence parameterizations, and particle trajectory models have been encouraged.

Thursday's session will focus on the engineering aspect of Lagrangian data, analysis methods and present/future Lagrangian-based sensor technology. Contributions on error characteristic of Lagrangian measurements, calibration methods, new Lagrangian instruments, and comparisons with Eulerian measurements and with simulated Lagrangian trajectories have been encouraged.

Friday's session will focus on assimilating Lagrangian data into both Eulerian models and Lagrangian particle models for nowcasts and forecasts. Contributions on applied Lagrangian prediction (search and rescue operations and pollution dispersion), optimizing the Lagrangian information in float observations for assimilation into Eulerian models, and sampling design have been encouraged

We wish you an interesting and fruitful meeting and a pleasant stay in this beautiful island!

Annalisa Griffa
Arthur Mariano
Tamay Ozgokmen
Enrico Zambianchi

Monday

8:45 am to 9:00 am **Welcome to the Ischia LAPCOD Meeting**
Opening remarks by Enrico Zambianchi, *Istituto Universitario Navale*

9:00 am to 12:15 pm **Observations and biological applications.**
Moderator: Arthur Mariano, *University of Miami*

9:00 am A101 Spreading of Mediterranean Water around the Iberian Peninsula
Amy Bower, Nuno Serra, Isabel Ambar
9:15 am A102 A Multidisciplinary Lagrangian Survey of the Spreading of Surface Low Salinity Waters along the Catalan Current in June 2000. Preliminary Results
Jordi Salat, Ana Sabates, Mikel Latasa, Montserrat Vidal, Beatriz Diez, M. Pilar Olivar, Mikhail Emelianov, Celia Marrase, Cristina Roldan, Balbina Moli, Arturo Castellon, Vanessa Balague
9:30 am A103 Circulation in the Algerian basin sensed by subsurface floats
P. Testor, J.C. Gascard
9:45 am A104 Lagrangian Studies of the Upper Ocean Circulation in the northern North Atlantic
T. Rossby, A. Bower, P. Richardson, M. Prater, H. Zhang
10:00 am A105 Eddy-mean flow decomposition and eddy-diffusivity estimates in the tropical Pacific Ocean
Sonia Bauer, Mark Swenson, Annalisa Griffa, Arthur Mariano
10:15 am A106 Very-High Resolution Mapping of Surface Currents
L.K. Shay, H. Peters, A.J. Mariano, T.M. Cook, E.H. Ryan, T. Ozgokmen
11:30 am A107 Spatial and temporal variability of flow regimes in the Caribbean Sea: Results from surface drifter trajectories
Kevin D. Leaman, Zulema Garraffo, W. Douglas Wilson

10:45 am Short Break (30 minutes)

11:15 am A201 Long distance dispersal versus local retention as a means of replenishing Caribbean marine fish populations
Robert K. Cowen, C. B. Paris, Kamazima M. M. Lwiza, D.B. Olson
11:30 am A202 A Lagrangian Approach to the Study of Primary Production
Daniela Cianelli, Maurizio Ribera d'Alcala', Enrico Zambianchi
11:45 am A203 Population dynamics advected by chaotic flows: a discrete-time map approach
Cristobal Lopez, Emilio Hernandez-Garcia, Oreste Piro, Angelo Vulpiani and Enrico Zambianchi
12:00 pm A204 Full Lagrangian Approach for Numerical Modelling of Collisionless Particle-Phase Flow Field in Non-Isothermal Two-Phase Boundry Layer discrete-time map approach
Natalia Tarasova, Yury Tsirkunov

12:15 pm to 1:00 pm **Favorite Lagrangian Trajectories**
Moderator: Arthur Mariano, *University of Miami*
Favorite Lagrangian trajectories from the archives will be presented by a number of scientists.

1:00 pm to 2:30 pm **Lunch Break**

2:30 pm to 5:00 pm **Monday Poster Session**

3:30 pm to 5:00 pm **Introduction to Working Groups**
Discussion lead by Arthur Mariano, *University of Miami*

5:00 pm to 7:30 pm **Ice Breaker**

Tuesday

8:45am to 1:00 pm **Theory of dispersion/transport/mixing.**
Moderator: Annalisa Griffa,
University of Miami, Consiglio Nazionale Ricerche(CNR)/ IOF

8:45 am B101 Closure problems in stochastic modelling of turbulent dispersion
A. Maurizi and F. Tampieri
9:00 am B102 Parameterization of dispersion in two-dimensional turbulence
C. Pasquero, A. Provenzale, A. Babiano
9:15 am B103 Dispersion processes in a semi-enclosed basin: probability distribution of the number of particles in the basin
G. Buffoni
9:30 am B104 Non Asymptotic Properties of Transport and Mixing
Angelo Vulpiani
9:45 am B105 Modeling Material Transport in the Ocean Gyres
Pavel Berloff, James McWilliams
10:00 am B106 The effect of the inertial frequency in the lagrangian tracer dispersion properties
V. Rupolo
10:15 am B107 Experimental Evidence of Chaotic Advection in a Convective Flow
S. Espa, G. Boffetta, M. Cencini and G. Querzoli
10:30 am B108 Modeling particle trajectories with a hybrid model using standard fields
Nathan Paldor, Yona Dvorkin

10:45 am Short Break (30 minutes)

11:15 am B201 Dynamical Systems Analysis of Transport in Flows Defined as Data Sets I:
S. Wiggins, C. Coulliette, K. Ide, Francois Lekien
11:30 am B202 Dynamical Systems Analysis of Transport in Flows Defined as Data Sets II: Eulerian Transport
K. Ide, S. Wiggins
11:45 am B203 Interactions of the Loop Current and adjacent rings in the Gulf of Mexico
C.K.R.T. Jones, L. Kuznetsov, M. Toner, A.D. Kirwan, Jr., L. Kantha, J. Choi
12:00 am B204 Lagrangian coherent structures and mixing in geophysical turbulence
George Haller
12:15 pm B205 Laboratory Experiments on Transport of Passive Tracers by Coherent Vortices
L. Montabone, H. Didelle, C. Giraud, A. Longhetto, A. Provenzale
12:30 pm B206 Lagrangian residual currents and their impact on suspended particulate matter transport
Susanne Rolinski
12:45 pm B207 FEM meets FDM - Conversion of velocities between two grid structures and transport of particles
Susanne Rolinski, Georg Umgiesser

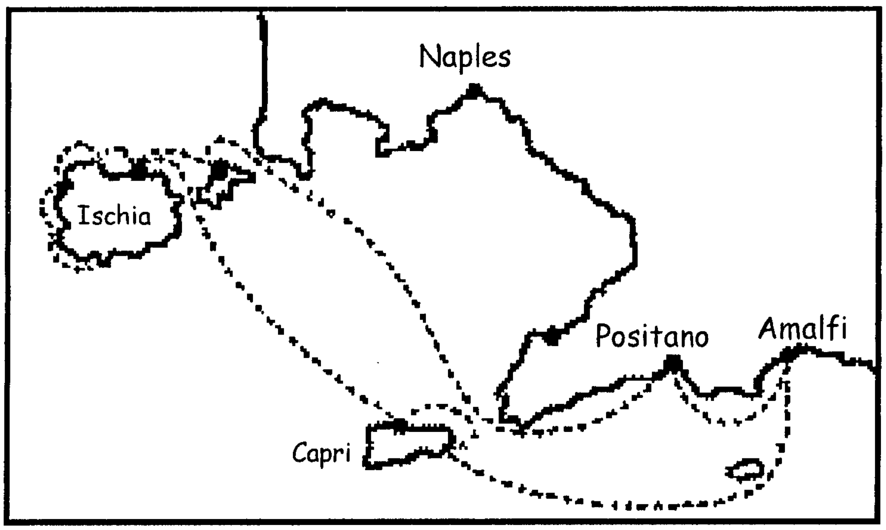
1:00 pm to 2:30 pm **Lunch Break**

2:30 pm to 5:00 pm **Tuesday Poster Session**

3:30 pm to 5:00 pm **Continuation of Working Groups**
Small group dicussions.

Wednesday

8:30 am to 6:0 pm **A day of interactions via a group social activity.**
A boat trip to the island of Capri, to Amalfi and to Positano is planned.



Thursday

8:45 am to 1:00 pm **Lagrangian instruments and data analysis techniques.**
Moderator: Enrico Zambianchi, *Istituto Universitario Navale*

8:45 am C101 Direct Measurements of Eddy Diffusivity in the Ocean
Maria O. Bezerra and Jose M. Redondo
9:00 am C102 Single particle and relative dispersion in the North Atlantic from isopycnal RAFOS float observation
Huai-Min Zhang, Tom Rossby, Dave Hebert, Mark Prater
9:15 am C103 Isopycnal floats as platforms for in-situ studies
T. Rossby, P. Lazarevich, M. Prater, H. Zhang, D. Hebert
9:30 am C104 Tracing the Mediterranean thermohaline circulation as it results from GCM simulations
V. Rupolo, D. Iudicone, V. Artale and R. Santoleri
9:45 am C105 Finite-scale Lyapunov analysis of Lagrangian trajectories from Mediterranean GCM simulations
D. Iudicone, G. Lacorata, V. Rupolo, R. Santoleri, A. Vulpiani
10:00 am C106 Can general circulation models be assessed and enhanced with drifter data ?
M. Toner, A.D. Kirwan, L. Kantha, J. Choi
10:15 am C107 POP Model Evaluations Using North Atlantic WOCE Drifter Data
Julie McClean and Pierre-Marie Poulain
10:30 am C108 Comparison of Lagrangian data in a high resolution North Atlantic model with in-situ drifter data
Z.D. Garraffo, A.J. Mariano, A. Griffa, C. Veneziani, E. Chassignet

10:45 am Short Break (30 minutes)

11:15 am C201 Statistical errors in estimating mean flow from Lagrangian data
A. Griffa, Z. Garraffo, A.J. Mariano, E. Chassignet
11:30 am C202 Lagrangian Analysis Techniques to Estimate Adriatic Sea Surface Circulation Statistics
Pierre-Marie Poulain
11:45 am C203 Entropic Analysis of Lagrangian Mixing at Varying Temporal Resolution
Markus Abel, Guglielmo Lacorata, Angelo Vulpiani
12:00 am C204 Advective Transports in Monterey Bay, Part I: HF Radar-Derived Current Fields
J.D. Paduan, M.S. Cook, C. Whelan, A.D. Kirwan, Jr., B.L. Lipphardt, Jr.
12:15 pm C205 Advective Transport in Monterey Bay, Part II: Flow Charactersitics
A.D. Kirwan, B.L. Lipphardt, C.E. Grosch, J.D. Paduan, C. Coulliette, J. Hatfield, S. Wiggins
12:30 pm C206 Advective Transport in Monterey Bay, Part III: Dynamical Systems Analysis
C. Coulliette, J. Hatfield, S. Wiggins, A.D. Kirwan, B.L. Lipphardt, Jr., C. Grosch and J. Paduan
12:45 pm C207 Dynamical Systems Approach to Lagrangian Transport: Fluxes and Barriers in a Double Gyre Flow
Francois Lekien, Kayo Ide, Stephen Wiggins

1:00 pm to 2:30 pm **Lunch Break**

2:30 pm to 5:00 pm **Thursday Poster Session**

3:30 pm to 5:00 pm **Continuation of Working Groups**
Small group dicussions.

8:00 pm **Social Dinner**

Friday

8:45 am to 11:00 am **Assimilation of Lagrangian data and predictability of trajectories.**
Moderator: Tamay Ozgokmen, *University of Miami*

8:45 am	D101	Reconstructing Basin-Scale Eulerian Velocity Fields from Simulated Drifter Data *A. C. Poje, M. Toner, A. D. Kirwan, Jr., C.K.R.T. Jones, B. L. Lipphardt, Jr., C. E. Grosch*
9:00 am	D102	Mathematical Modeling Experiments to Estimate the Distribution of Tracer and Water Particle Movement *Erdem Sayin*
9:15 am	D103	Sediment particle transport prediction, based on the Random Walk simulation *Y. Savvidis, V.H. Kourafalou, Y. Krestenitis and C. Koutitas*
9:30 am	D104	Predictability of Drifter Trajectories in the Tropical Pacific Ocean *Tamay M. Ozgokmen, Leonid I. Piterbarg, Arthur J. Mariano and Edward H. Ryan*
9:45 am	D105	Assimilation Experiments with Simulated Drifter Data as Velocity Measurements *T.M. Chin*
10:00 am	D106	Lyapunov Exponents for Stochastic Flows Modeling the Upper Ocean Lagrangian Motion *Leonid I. Piterbarg*
10:15 am	D107	Relation between Lagrangian Stochastic Models and Equations of Fluid Mechanics *Leonid I. Piterbarg and Boris Rozovskii*
10:30 am	D108	Lagrangian coordinates for ocean data assimilation *J.L. Mead, A.F. Bennett*
10:45 am	D109	The role of coherent Lagrangian structures in turbulent transport *C. Coulliette, N. Ju, A.M. Reynolds, S. Wiggins*

11:00 am to 12:00 am **Friday Poster Session**

12:00 am to 1:30 pm **Summary of Working Groups**

1:30 pm to 2:30 pm **Lunch Break**

Session A Abstracts

A101

Spreading of Mediterranean Water around the Iberian Peninsula

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(Abstract received 07/26/2000 for session A)

The Mediterranean salt tongue is one of the most prominent features of the North Atlantic at the thermocline level, resulting from the overflow of saline Mediterranean Water through the Strait of Gibraltar. The Mediterranean Water (MW) initially flows in a narrow boundary undercurrent along the continental slopes of Spain and Portugal. Starting near Cape St. Vincent, the MW spreads laterally into the interior via submesoscale vortices (meddies) and other processes. Our understanding of how MW spreads into the Atlantic has been mainly inferred from hydrographic observations. Here we focus on direct measurements of MW spreading with subsurface acoustically-tracked floats that were sequentially launched in the undercurrent south of Portugal. Based on these observations, we find that the Lagrangian integral time scale is relatively short, 3-4 days, compared to the western North Atlantic (10 days). Eddy kinetic energy levels are high in the undercurrent south of Portugal, exceeding 100 cm^2/s^2, possibly due to the flow of the undercurrent past several large submarine canyons. Transforming the float velocities into bathymetric coordinates, it is clear that the undercurrent changes character abruptly around Cape St. Vincent, evolving from a strong jet-like current with peak mean speed of 15-20 cm/s, to a weaker current with peak speeds of only 5-10 cm/s. As well as being sites of meddy formation, Cape St. Vincent and the Estremadura Promontory are regions of enhanced eddy kinetic energy for the background flow field. The float tracks also show how the presence of meddies forming along the slope can divert the undercurrent offshore, representing an indirect effect of meddies on MW spreading.

A102

A Multidisciplinary Lagrangian Survey of the Spreading of Surface Low Salinity Waters along the Catalan Current in June 2000. Preliminary Results

Jordi Salat, Ana Sabates, Mikel Latasa, Montserrat Vidal, Beatriz Diez, M. Pilar Olivar, Mikhail Emelianov, Celia Marrase, Cristina Roldan, Balbina Moli, Arturo Castellon, Vanessa Balague
Institut de Ciències del Mar
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(Abstract received 07/27/2000 for session A)

Summary In this communication we present the preliminary results of a Lagrangian survey carried out during last June along the Catalan current, from the Gulf of Lions to Barcelona. According to previous studies, at the end of spring a water mass of relatively low salinity, originated in the Rhone River plume, is spreading widely through the surface of the Gulf of Lions. Part of this water is captured and advected by the NW Mediterranean shelf-slope current along the shelf break off the Catalan coast. The first part of the ARO-2000 cruise was devoted to a Lagrangian survey of this water mass, along the track of 3 Argos drogues, adapted to follow the current at a depth around 10 m. They were initially placed at the shelf break of the Gulf of Lions within the low salinity surface waters above mentioned. They were left to follow these surface waters while being advected by the shelf-slope current along ca. 200 km, during 10 days. The area was covered by a series of 68 sampling stations distributed in 9 sections, from the coast to the end of the continental slope. Each section was planned to cross the path of the drifters in such a way to meet the actual position of the drifters. Accordingly 9 of the stations followed the evolution of the same surface water parcel. All along the shiptrack, TS analysis of surface water and ADCP measurements were obtained. A CTD cast and zoo- and ichtyoplankton trawls were performed at all stations. In all of the stations corresponding to the advected water an exhaustive sampling of water was done to cover: nutrient (organic and inorganic), chlorophyll, microbial plankton and their activity, and phytoplankton.

A103

Circulation in the Algerian basin sensed by subsurface floats

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(Abstract received 07/28/2000 for session A)

Fourteen subsurface floats drifting at about 600m depth, have been located acoustically from July 1997 to July 1998 in the Algerian basin. In contrast with eulerian current measurements, floats trajectories

highlight several important features at very different scales and offer new insights of the basin circulation. They reveal a dominant large scale cyclonic circulation (250km diameter and 3 months period) at 600m depth, that we will call the Algerian Gyre. This gyre has a strong seasonal variability. It appears to be fairly well developped late fall-early winter and much less reduced in summer. Very few mesoscale eddies are evidenced at this depth although the circulation in this basin was thought to be dominated by mesoscale anticyclonic eddies (Algerian Eddies) at all depths. Floats also revealed anticyclonic Submesoscale Coherent Vortices (20km of diameter, few days period and more than 1 year lifetime) migrating around the large cyclonic Algerian Gyre and carrying on Levantine Intermediate Water into the interior of the basin. LIW branch flowing from the Tyrrhenian Sea towards the Liguro-Provencal basin alongslope of Sardinia is also well evidenced from floats trajectories. The Algerian Gyre is characterised at zero order in Rossby number by a vorticity balance involving planetary vorticity and bottom topography since floats are closely following f/H isocontours. Relative vorticity being of the same order as d(1/H)/dt and/or d(f)/dt, should be precisely estimated in order to speculate about the origin of the Gyre and its variability. This could be obtained by redistributing currentmeters array in order to combine efficiently lagrangian and eulerian informations.

A104

Lagrangian Studies of the Upper Ocean Circulation in the northern North Atlantic

Rossby, T., A. Bower, P. Richardson, M. Prater, H. Zhang
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(Abstract received 07/31/2000 for session A)

As part of the WOCE Atlantic Climate Change Experiment (ACCE), 115 isopycnal floats were deployed in the Subpolar Front just west of the mid-Atlantic ridge and along the eastern margin to study the spreading and mixing of these upper ocean waters into the NE Atlantic Ocean. Drifting on an isopycnal corresponding to sigma-t = 27.5, these acoustically tracked floats are giving us unprecedented information on the pathways of spreading, cross-frontal exchange and mixing processes between the three major water masses on this isopycnal: subtropical waters from the Gulf Stream and North Atlantic Current, Labrador Sea waters and the waters along the eastern margin from the Mediterranean.

Several striking features stand out. First, the eastward penetration of subpolar waters through the Charlie Gibbs Fracture Zone (CGFZ) and their spreading along two principal pathways to the north: one heading NE into the northern Iceland Basin west of Rockall/Hatton Bank and the other turning (north)west rather sharply towards the Reykjanes Ridge. This retroflection of waters from the mid-Atlantic ridge appears to be in response to "blocking" by the eastward spread of Labrador Sea waters penetrating east through the CGFZ. Second, none of the floats continue into the Nordic Seas even though they had time to do so. Instead all floats in the northern Iceland Basin turn west and south along the Reykjanes Ridge before turning back north and into the Irminger Sea. This begs the question from where the waters entering the Norwegian Sea along the Iceland-Faroes Front come. Third, the isopycnal floats exhibit very strange depth variations in the vicinity of the Rockall Bank complex where waters from the SW along the Subpolar Front and the SE from the Mediterranean come into contact, interleave and mix. Numerous examples of submesoscale eddy activity can be noted, including the formation of Œmeddies, at higher latitudes than previously thought. Thes e observations clearly show the very important role played by topography to currents on all scales: the mean flow, eddy activity and mixing processes.

A105

Eddy-mean flow decomposition and eddy-diffusivity estimates in the tropical Pacific Ocean

Sonia Bauer, Mark Swenson, Annalisa Griffa, Arthur Mariano
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(Abstract received 10/07/2000 for session A)

Eddy diffusivity is a statistic that provides a quantitative measure of the diffusive transport caused by mesoscale motions. The principal objective of this study is to estimate eddy diffusivities of the surface velocity field in the tropical Pacific Ocean. The observations are satellite-tracked drifting buoys spanning the years 1979 through mid-1996. The data were assembled and distributed by the data acquisition center at the NOAA Atlantic Oceanographic and Meteorological Laboratory (AOML) and were obtained as part of the Equatorial Pacific Ocean Climate Study (EPOCS) and World Ocean Circulation Experiment--Tropical Ocean-Global Atmosphere (WOCE-TOGA) programs. The

tropical Pacific surface current system is characterized by: 1) nonstationarity due to rapid response time of equatorial and near-equatorial dynamics; 2) strong meridional shear in the large-scale mean; and 3) an energetic mesoscale velocity component. Taylor (1921) defined eddy diffusivity as the integral of the autocovariance of Lagrangian eddy velocities -- requiring both stationary and homogeneous statistics of the eddy field. Eddy velocities were obtained in this study by removing the splined mean field to eliminate mean shear as described in Part 1 (Bauer, et al 1998) and binned spatially to group data that have similar dispersion characteristics. Temporal partitions were made to create stationary eddy statistics.

Zonal diffusivity estimates vary with latitude from about $5x10^7$ to $76x10^7$ cm^2/s. Largest estimatesare in regions of strong meridional shear and large eddy variance between 4°S and 10°N. However, meridional diffusivity estimates are nearly constant throughout the tropics varying from $2x10^7$ to $9x10^7$ cm^2/s. Simple autoregressive models provide the analysis with estimates of Lagrangian integral time scale which is a measure of the turbulence decorrelation time scale. First order (AR(1)) and second order (AR(2)) autoregressive processes adequately describe the eddy transport statistics. All zonal eddy transport statistics and meridional statistics from low variance regions (generally poleward of 4°S and 10°N) can be modeled by AR(1) statistics modified by inertial wave oscillations. Meridional statistics of the near-equatorial regions (between 4°S and 10°N) are characterized by large meridional eddy variance associated in part with tropical instability waves (TIW's), and by low meridional diffusivity: Wave motion increases eddy variance but does not diffuse water parcels with periodic trajectory motion. Therefore, meridional eddy diffusivities are low in these regions and are modeled by AR(2) statistics.

An independent confirmation of the diffusivity estimates in the central and eastern Pacific was obtained by comparing tracer flux divergence computed from a parameterization using diffusivity estimates of our analysis and that from direct eddy Reynolds stress flux divergence. Our results show that diffusivity can be estimated for regions that have not been considered before because of lack of data and because of the complexities of the velocity field.

A106

Very-High Resolution Mapping of Surface Currents

L.K. Shay, H. Peters, A.J. Mariano, T.M. Cook, E. H. Ryan, T. Ozgokmen
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(Abstract received 08/24/2000 for session A)

The 4-D current experiment collected a suite of data in the coastal region off of Hollywood, FL during the summer of 1999. The primary data set is OSCR surface velocity data obtained at 250 m resolution. Comparisons to subsurface velocity measurements from ship-board and moored ADCPs reveal high correlations with rms differences of 7-9 cm/s depending upon the depth of the upper most bins. These surface velocity measurements data are space-time interpolated to a regular very-high resolution space-time grid, 100 m in the horizontal and 15 minutes in time. The complex dynamics are nonstationary, heterogeneous and significant events include submesoscale vortices, large lateral meandering of the Florida Current on time scales of hours, eddy merger and periods of strong anomalous southward flow. Dominated periods are 10 and 27 hrs and dominant spatial scales are on the order of 2-3 kms. Simulated Lagrangian trajectories, at the latitude of the Broward County Sewer Outfall, indicate that particles released at least 3 km offshore are mostly likely to leave the domain. The potential benefits of combining high resolution OSCR data with a dense array of drifters will also be discussed.

A107

Spatial and temporal variability of flow regimes in the Caribbean Sea: Results from surface drifter trajectories

Kevin D. Leaman[1], Zulema Garraffo[1], W. Douglas Wilson[2]
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(Abstract received 08/17/2000 for session A)

In the excess of 100 surface drifters have been launched using ships of opportunity into the Caribbean Sea over the last 2-3 years as part of the National Oceanographic Partnership Program (NOPP) Year of the Ocean (YOTO). All drifters are drogued at 15m and repart surface poritions and temperatures. Drifters launched into the eastern and northern Caribbean show a Broad westward drift with considerable evidence of both cyclonic and anticyclonic mesoscale eddies. This flow does not become more organized until drifters approach the Yucatan Channel. By contrast, drifters launched into the southwestern Caribbean (with assistance from the Colombian Navy) have shown the presence of a quasi-permanent cyclonic gyre known as the Panama-Colombian Gyre (PCG). This gyre exhibits considerable seasonal and shorter-term variability. Retention times for drifters launched in the PCG are order several months. Very few drifters from the open Caribbean find their way into the PCG; however, a large number of PCG drifters exit the PCG at various locations and times, and a significant number of these become trapped in shelf waters south of Cuba. This latter fact has implications for biological problems of larval transport and interconnectivity of coastal habitats. Observed drifter tracks are compared to numerical surface drifters "deployed" in a high-resolution isopycnic-coordinate numerical model. Similar seasonal variability is observed in both real and numerical drifter trajectories; in particular, a deformation of the flow field in late summer has been observed in the model as well as in two sequential years of drifter observations. Over longer periods, numerical drifter concentrations in the PCG decrease until a balance is achieved between northward Ekman advection and diffusion of drifters from the interior.

A201

Long distance dispersal versus local retention as a means of replenishing Caribbean marine fish populations

Robert K. Cowen, C. B. Paris, Kamazima M. M. Lwiza, D.B. Olson
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(Abstract received 08/24/2000 for session A)

Early models and evidence from genetics suggest that long distance dispersal of larvae is likely a common event leading to considerable population connectivity among distant populations. However, recent evidence strongly suggests that local retention is more the rule, and that long distance transport is likely insufficient to ecologically sustain marine populations. Here we examine the probability of larval dispersal to downstream islands within different regions of the Caribbean at varying distances from source populations. Coupling an isopycnic-coordinate numerical model with a Lagrangian random flight scheme describing larval sub-grid turbulent motion, we investigate the likelihood of particular circulation events transporting large numbers oflarvae to within 10 km radii of downstream populations and accumulating them over a year. We then examine the hypothesis that larvae of coral reef fishes capitalize on flow structures to be retained in the proximity of their native island. High-resolution biological and physical surveys of the pelagic processes affecting the larval phase of coral reef fishes were conducted on the western shore of Barbados to produce an integrated view of the local flow field. Using a similar coupled Lagrangian model parameterized to fit island circulation scales, we provide information on the formation, maintenance, and advection of larval patches by comparing, at different levels of behavior, predicted and observed larval distributions. Percentage of larvae retained in the Barbados near-field is also estimated.

A202

A Lagrangian Approach to the Study of Primary Production

Daniela Cianelli, Maurizio Ribera d'Alcala', Enrico Zambianchi
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(Abstract received 08/02/2000 for session A)

Results of a numerical model simulating the behaviour of phytoplankton cells are presented and discussed. The motion of the cells (or of their aggregates) develops along the vertical according to a turbulent velocity field simulating vertical dynamics within the mixed layer. In addition, the model describes a number of biological processes depending on the vertical position of the cells and on their individual physiological history. In particular, the energy source for the cell growth, occurring through photosynthesis, is represented by sun light, whose availability is a function of time, of the vertical position of the growing cell as well as of the other cells, because of the self-shading effect which is explicitely accounted for. Photoadaptation processes are also included in the model. The results show the relative importance of the different physico-biological factors affecting the phytoplankton cell behaviour.

A203

Population dynamics advected by chaotic flows: a discrete-time map approach

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(Abstract received 07/26/2000 for session B)

A discrete-time model of, chemically or biologically, active fields advected by a 2D chaotic flow is studied. Our approach is based on the use of a lagrangian scheme where *fluid particles* are advected by a *2d* symplectic map possibly yielding lagrangian chaos. Each *fluid particle* carries concentrations of

active substances which evolve according to another map which mimics the reaction or population dynamics. Specifically, a logistic map is used where the bifurcation parameter is space dependent, simulating a spatially nonhomogenous distribution of nutrients or of activators. Exploiting the analogies of this coupled maps (advection plus reaction) system with a random map, some features of the different Eulerian 2d spatial patterns of the active particles concentration are discussed. In particular, we address the problem of the different patterns that appear depending on the behavior of the maps ruling the lagrangian and reactive dynamics.

A204

Full Lagrangian Approach for Numerical Modelling of Collisionless Particle-Phase Flow Field in Non-Isothermal Two-Phase Boundry Layer

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(Abstract received 08/15/2000 for session B)

The fresh modification of the numerical method based on the Full Lagrangian Approach (FLA) is developed for calculation of particle-phase flow field in dilute gas-particles mixture flows. The collisionless "gas" of particles is treated as the continuum for which all basic equations including the continuity equation, the momentum equation and the energy equation are written in the Lagrangian coordinates. (The majority of researchers do not use the continuity equation in an explicit form changing it by some approximate relations. Such approach is also known as the Lagrangian one but it is not the FLA, of course.) When using the FLA one must calculate the components of the Jackobian of the Eulerian/Lagrangian transformation to obtain the density of the dispersed phase along particles' trajectories from the continuity equation. These components can be calculated by different ways, but in the present paper they are calculated by numerical differentiation of the Eulerian coordinates with respect to the Lagrangian ones using particles' parameters on several close trajectories. This way has advantages over any other one if the right-hand sides of the momentum and energy equations for a particle are very cumbersome. Such situation takes place for fine particles moving inside the non-isothermal boundary layer because of very complicated gas-particle interaction in this case, and it is studied in the paper. The developed method provides very high spatial resolution.

Posters Only Section

A301

Lagrangian dynamics of the Pacific Sector of the Southern Ocean

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(Abstract received 08/02/2000 for session A)

Surface and subsurface Lagrangian trajectories gathered in the Pacific Sector of the Southern Ocean in the framework of the activities of the Italian National Programme for Antarctic Research (PNRA) are studied. Surface drifters have been routinely deployed along the route New Zealand - Ross Sea once a year and have proved to efficiently track the axis of the Antarctic Circumpolar Current. A fraction of the drifters undergoes a regime of strong eddy activity and overshoots to the north, getting caught in the South Pacific Current and, eventually, in the subtropical gyre circulation of the Southern Pacific. The data are presented both in terms of pseudoeulerian and stricly Lagrangian analyses. An attempt to characterize the vorticity behaviour in terms of the f/H ratio calculated along the trajectories is also carried out, with aparticular focus on the crossing of the Pacific-Antarctic Ridge, which tipically occurs in a vorticity balanced fashion. The effect of the presence of ice coverage is also investigated.

A302

Mesoscale Vortices and the Paradox of the Plankton

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Coexistence of competitive species is severely limited by the availability of resources and the characteristics of the environment. In particular, the so-called ``competitive exclusion principle" states that, at equilibrium, the number of coexisting species cannot be larger than the number of resources they compete for. On the other hand, many ``in situ" observations have revealed prolonged coexistence of a large number of competitive plankton species, a phenomenon known as ``the paradox of the plankton". Here we investigate this problem and show that ocean mesoscale vortices generate transport barriers and incomplete horizontal mixing, allowing for a prolonged survival of the less-fit

species even for fully homogeneous resource distributions. In such a situation, the temporarily less-fit plankton species are protected from competition by the action of the vortices.

A303

The California Undercurrent as observed with Lagrangian subsurface floats and in a near-global ocean model simulation

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During the period 1992--1998 38 isobaric RAFOS floats were deployed to sample the subsurface flow of the California Undercurrent. The deployments, released over the California continental slope west of San Francisco, have shown the robust year--round poleward flow of the Undercurrent. Two other types of flow have been seen: a region of weak flow with little net displacement just west of the California Undercurrent, and an active westward propagating eddy field. This eddy field appears to be the primary mechanism for moving floats from the Undercurrent into the ocean interior. The observations and statistics from the RAFOS floats are compared with Lagrangian estimates of particles tracked in a global high resolution ocean simulation in order to evaluate the fidelity of the model along an eastern boundary. The results show that the model reproduces the general character of the flow reasonably well, but underestimates both the mean and eddy energies by a substantial amount.

Section B Abstracts

B101

Closure problems in stochastic modelling of turbulent dispersion

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(Abstract received 08/01/2000 for session B)

In the application of Lagrangian Stochastic Models (LSM) for turbulent dispersion of passive tracers a closure problem arises in the determination of the shape of the probability density function (pdf) of Eulerian velocity. In this paper commonly used closure schemes are reviewed and the importance of using the maximum missing information (mmi) pdf is outlined. Analysis of available data from literature on 3rd and 4th order pdf moments shows the need for using non Gaussian pdfs and suggests a possible closure through a relationship between skewness (S) and kurtosis (K)

B102

Parameterization of dispersion in two-dimensional turbulence

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(Abstract received 07/31/2000 for session B)

The classical approach to the study of tracer advection in large-scale geophysical flows is based on separating the effects of the mean flow (that is slowly variable in space and time) from that turbulent dynamics acting on smaller scales. When it is not resolved, the turbulent velocity is often considered as a random variable, and its effects are usually described in term of an eddy diffusivity. It has been shown in the past years that the presence of coherent structures may modifie the dispersion properties. We here study the dispersion of tracers in a statistically stationary two-dimensional turbulent field, through the analysis of statistical characteristics as the dispersion coefficient, the distribution of displacements, the velocity autocorrelation function and the first exite time. We then develope a non linear stochastic model which takes into account of the nonlocal effects coherent structures have on the velocity field. We show, on the other hand, that the modelization of the advecting field as a sum of coherent vortices fails in reproducing the turbulent dynamics, indicating that both the coherent structures and a lower energy vorticity component (the "background") are necessary for reproducing the advecting field. The parameterization, which provides a large improvement in the description of the turbulent statistics, uses few parameters, whose values can be set from observative lagrangian properties, such as autocorrelation function and velocity distribution.

B103

Dispersion processes in a semi-enclosed basin: probability distribution of the number of particles in the basin

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(Abstract received 07/12/2000 for session B)

A number n of particles are instantly released in a semi-enclosed basin at a given point and subsequently dispersed by water motions. The dispersion processes considered here imply that all the particles eventually leave the basin. It is assumed that there is no interaction between the partcles, and that the probability c(t) of finding a particle in the basin at time t is the same for all the particles. Thus, the histories of the particles are independent realizations of the same process. Let N(t) be the random variable "number of particles in the basin at time t". It follows that the probability distribution of the events N(t)=i, 1=0,1,...,n, is a binomial distribution. The basic properties of the stochastic process N(t) are illustrated: time dependence of the probability distribution, and of its numerical characteristics mean value and variance; when the binomial distribution can be approximated by the Poisson distribution; the probability distribution of the events "at least (most) i particles are in the basin at time t". Numerical experiments have been performed by applying Lagrangian models to various sample problems, confirming the results of the theoretical analysis.

B104

Non Asymptotic Properties of Transport and Mixing

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(Abstract received 07/20/2000 for session B)

We study relative dispersion of passive scalar in non-ideal cases, i.e. in situations in which asymptotic techniques cannot be applied; typically when the characteristic length scale of the Eulerian velocity field is not much smaller than the domain size. Of course, in such a situation usual asymptotic quantities (the diffusion coefficients) do not give any relevant information about the transport mechanisms. On the other hand, we shall show that the Finite Size Lyapunov Exponent, originally introduced for the predictability problem, appears to be rather powerful in approaching the non-asymptotic transport properties. This technique is applied in a series of numerical experiments in simple flows with chaotic behaviors, in experimental data analysis of drifter and to study relative dispersion in fully developed turbulence.

B105

Modeling Material Transport in the Ocean Gyres

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Material spreading and mixing by oceanic mesoscale eddies are analyzed in an idealized, numerical model of the wind-driven, mid-latitude ocean circulation. The analyses are based on ensembles of Lagrangian particle trajectories. The single-particle dispersion, which describes the spreading, is generally anisotropic and inhomogeneous, and in most places it is not diffusive (i.e., not linear in time) during intermediate-time intervals after release. A hierarchy of inhomogeneous and non-stationary stochastic models of material transport is rigorously formulated, its properties are described, and each model is fitted to an eddy-resolving solution of idealized, mid-latitude ocean gyres. The models provide more skillful parameterizations of the sub-grid-scale material transport induced by unresolved mesoscale eddies than the commonly used eddy-diffusion model.

B106

The effect of the inertial frequency in the lagrangian tracer dispersion properties.

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(Abstract received 07/28/2000 for session B)

The effect of the inertial frequency in the lagrangian dispersion properties is studied by means analysis of lagrangian trajectories by simplified models and GCM simulations in presence of spatially variyng diffusivity field.

B107

Experimental Evidence of Chaotic Advection in a Convective Flow

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Lagrangian motion in a quasi-two dimensional time dependent, convectiveflow is studied at different Rayleigh numbers (Ra). Particle TrackingVelocimetry technique is used to reconstruct Lagrangian trajectories ofpassive tracers. In the investigated range of the control parameter (6.87·10^7;2.17·10^9), we study an intermediate regime in which analmost periodic Eulerian flow is observed. It is well known that in this regime, Lagrangian motion of passive particles can be very complex due to chaotic advection. As a matter of fact, particle trajectories can display Hamiltonian chaos and, therefore, strong sensitivity to initial conditions. Dispersion phenomena occurring in the tank are investigated in a Lagrangian framework. The classical way of looking at the relative dispersion by computing average separation at fixed time is comparedwith an alternative method known as Finite Size Lyapunov Exponent (FSLE) technique consisting in the evaluation of average rate of particle separation time at fixed scale.

The obtained results can be exemplifying in approaching geophysical problems characterised by a not sharp separation between the scale of mthe velocity field and the dimension of the domain allowing us to discuss about the better way of describing spreading of pollutants in closed basins.

B108

Modeling particle trajectories with a hybrid model using standard fields

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A hybrid model is proposed for calculating the observed trajectories of constant level particles (e.g. balloons) in the atmosphere using standard meteorological fields. Particles in the model are advected by a linear combination of the Eulerian ECMUF winds exptrapolated to the desired level and a correctional velocity calculated by integrating the acceleration due to pressure- gradient, the Coriolis force and a drag force modeled by Rayleigh friction term. The model trajectories are at least twice as close to trajectories observed during the EQUATURE experiment conducted in the summer of 1998 than those that result from advection by the airflow. This significant improvement is achieved with a 15% weight of the correctional velocity i.e. when the balloon's velocity is about 85% that of the surrounding airflow. The relaxation time of the Rayleigh friction coefficient is on the order of 1 day in all cases. In addition to the individual best fit of each of the observed trajectories, the model yields a global, single best fit, set of parameter values in which the model trajectories are 33% closer to the observed ones compared to the advection by the airflow. The parameter values of this global best fit set are only slightly different from the three individual sets. A simple, Stokes drift, model where the balloon velocity is allowed to vary slightly from that of the airflow for short times (i.e. where the drag relaxes the balloon to the air speed) yields trajectories that are worse than those of the pure advection for realistic values of the relaxation coeeficient.

B201

Dynamical Systems Analysis of Transport in Flows Defined as Data Sets I:

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In the past five years there have been significant advances in dynamical systems theory to the point where the framework can now be utilized in the context of "real" problems. In this talk we will briefly describe the dynamical systems framework for Lagrangian transport. In particular, we will show how data sets, such as those derived from remote sensing observations (such as high frequency radar arrays) or the output of a large scale numerical computation, can be viewed as dynamical systems. We will illustrate these ideas by introducing several examples; transport in a coastal system using a velocity field obtained experimentally from high frequency radar measurements and transport in a wind driven double gyre system. The point of view of a dynamical system as a data set gives rise to new mathematical problems in the theory of dynamical systems. These will be briefly mentioned, but the focus will be on showing how dynamical systems theory applies and gives new insight and results on transport and predictability of transport processes. Finally, we will discuss other problems where the dynamical systems approach to transport may have a major impact in the future.

B202

Dynamical Systems Analysis of Transport in Flows Defined as Data Sets II: Eulerian Transport

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Eulerian transport measures net amount of fluid particles and properties such as temperature and salinity, which migrate from one region to another across a stationary boundary over a time interval. In this talk we present a new theoretical framework for Eulerian transport where the stationary boundary is defined by a reference streamline based on dynamical systems approach. Our theory provides us with quantitative as well as geometrical information concerning Eulerian transport across any reference streamline over a finite or infinite time interval. Its relation to Lagrangian transport theory can be rigorously shown when the stationary boundary is chosen to compute the terminal transport between kinematically distinct flow regions. We demonstrate our theory using a data set obtained by numerical simulation of mid-latitude wind-driven ocean circulation. Finally we discuss future applications of Eulerian transport in physical oceanography.

B203

Interactions of the Loop Current and adjacent rings in the Gulf of Mexico

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Evolution of the Loop Current and the adjacent mesoscale rings have been investigated over a 20-day period, starting June 1, 1998. Observational data (altimetry, drifters) and a model velocity field (output of a Princeton Ocean Model of the Gulf of Mexico) were used in the study. The coherent structures were identified in the Lagrangian framework by means of Effective Invariant Manifolds (EIM). The Lagrangian approach provides detailed information about ring interaction and reveals features of the ring dynamics hidden in the Eulerian picture. During the observation period, a new ring was formed in the meander of the LC (area 2x10^4 km) and a large

anticylonic ring west of it (area 7x10^4 km) was cleaved by a southbound cyclonic eddy. The intensity of water exchange between the rings and the ambient water varied considerably among the rings: cyclonic rings experienced active mixing along the boundary, whereas the anticyclonic ones were relatively isolated. Available drifter trajectories are in qualitative agreement with the results of the Lagrangian analysis based on the model velocity field.

B204

Lagrangian coherent structures and mixing in geophysical turbulence

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(Abstract received 08/16/2000 for session B)

While the emergence of coherent structures in two-dimensional turbulence is well known, their description has primarily been Eulerian. In this talk we introduce a new, Lagrangian approach to coherent structures. We discuss an analytic result, a Lagrangian version of the Okubo-Weiss criterion, that enables one to extract coherent structure boundaries with great precision from experimental/numerical data. This criterion is Galilean invariant and hence eliminates the use of instantaneous stagnation points or other frame-dependent Eulerian features from the analysis of velocity data. We show applications to baropropic turbulence simulations. Finally, we discuss three-dimensional extensions and their applications.

B205

Laboratory Experiments on Transport of Passive Tracers by Coherent Vortices

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A set of laboratory experiments, meant to study the transport of passive tracers by coherent vortices, have been carried out in the large-scale rotating tank (14 m in diameter) of the Coriolis Laboratory (LEGI-IMG) in Grenoble, France. In each experiment, we have obtained long-lived coherent structures in a shallow water, quasi two-dimensional set-up, for different values of the Rossby number and of the water depth. Particle Image Velocimetry and Laser Induced Fluorescence have been used in order to get both qualitative information on the turbulent field and quantitative velocity measurements. Direct Lagrangian information at fixed depth was provided by a few float-like tracers released either inside or outside vortices. After interpolation in time, the experimental velocity fields have been used to numerically integrate the motion of passive tracer particles. Here we discuss the results of the analysis of the trajectories of the float-like tracers as well as the Lagrangian data obtained by the numerical integration using experimental Eulerian fields.

B206

Lagrangian residual currents and their impact on suspended particulate matter transport

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High turbidity zones are common phenomena in tidal estuaries. Suspended particulate material (SPM), which causes the turbidity, is accumulated at the landward side of the salt intrusion and also in places in the freshwater region. Accumulations in the tidal River Elbe are reproduced with a three-dimensional Lagrangian model for the transport, deposition and resuspension of SPM.

Subject of this paper are accumulations in the freshwater region. Different approaches to determine residual currents are applied out in order to identify current structures that are related to SPM accumulations. Classical approaches of describing Lagrangian residuals result in convergence in the mixing region in the waterway. They give no indication on accumulations in regions without density stratification. Eddies close to areas of high SPM concentrations are found when the analysis takes into account horizontal gradients of current properties.

B207

FEM meets FDM - Conversion of velocities between two grid structures and transport of particles

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In the framework of the european project F-ECTS, a three-dimensional Lagrangian model for suspended particulate matter (SPM) transport is applied to Venice Lagoon. Purpose of the project is ther

simultaneous determination of macroalgae growth and SPM transport and their feedbacks. Main difficulty was the adaptation of velocities from an existing hydrodynamical model with finite element structure to a finite difference scheme in order to apply the existing SPM transport model. This paper describes the modifications and lists the additional information which is necessary for the transport of particles with the transformed currents. Bathymetry values have to be recalculated into the volume conserving equivalent and besides depths, the area which is covered per grid cell, has to be known. Given the transport over the boundary of a rectangular box wall, the length of the wall is needed to determine the velocity at the relevant grid point. To prevent particle presence in the entire box area, where only a fraction is covered the FEM structure, particle movements have to be restricted to a smaller box size. Therefore, 'wet' box areas are transformed into rectangulars of equivalent area which box lengths are prescribed for particle positions. First results are shown and interpreted with this approach.

Section C Abstracts

C101

Direct Measurements of Eddy Diffusivity in the Ocean

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We have used a novel techniques to study turbulent diffusion by means of digital processing of images taken from remote sensing and video recordings of the sea surface. The use of image analysis allows to measure variations of several decades in horizontal diffusivity values. There is an increase of diffusivity with wave height but only for large Wave Reynolds numbers. Other important factors are wind speed and tidal currents. The horizontal diffusivity shows a marked anisotropy as a function of wave height and distance from the coast.

Measurements have been made near the coast in a series of field experiments done at the Trabucador beach in the Ebro Delta, south of Barcelona and in Brazil for a variety of weather conditions and there is a strong dependence of horizontal eddy diffusivities with the Wave Reynolds number as well as with the wind stress measured as the friction velocity from wind profiles measured at the coastline. These results have been published recently in Bezerra et al. 1998. Both efects are important and give several decades of variation of eddy diffusivities measured near the coastline (between 0.0001 and 2 m2/s). Longshore currents are also important near the coast. Experiments of dye diffusion such as those performed filming the evolution of sliks allow to characterize the ranges of Kx and Ky as a function of the distance to the coast and other environmental factors such as Wave height and frequency, wind stress, tides and mean currents.

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C102

Single particle and relative dispersion in the North Atlantic from isopycnal RAFOS float observation

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(Abstract received 08/01/2000 for session C)

Lagrangian observation techniques of the ocean have experienced rapid advancement in the last few decades. Isopycnal RAFOS floats make it possible to accurately track water parcel movements, and it is particularly useful in dynamic frontal regions where enhanced mixing and water property exchange can take place along tilting isopycnals that significantly intersect geopotential surfaces. Equipped with pressure, temperature and dissolved oxygen sensors, the floats, as roving current meters and hydrographers, can map out the ocean general circulation and property distributions on isopycnal surfaces. As Lagrangian particle followers, the floats provide water mass pathways and data for particle dispersion and turbulent mixing studies.

Isopycnal floats have been deployed in the Gulf Stream, North Atlantic Current (NAC), and Subpolar Front (SPF) regions in separated programs. In particular, significant numbers of the floats were deployed in pairs or triplets with the aim to study relative dispersion, especially in the recently completed ACCE (Atlantic Climate Change Experiment) field program. We present single particle and relative dispersion statistics from the above observations. Specifically, we discuss the mean and eddy decomposition, shear versus turbulent dispersion, the pdf (probability density function) distribution of the turbulent flow, and the laws governing the single and relative dispersion at different stages (i.e. different time and spatial scales). We discuss our results for different regions. For example, eddy kinetic energy (EKE) generally decreases from the Gulf Stream downstream to the Iceland Basin, but locally enhanced EKE was found over the Mid Atlantic Ridge, and south and west of the Rockall Plateau where the NE-flowing NAC/SPF water encounters the Mediterranean water. Compared to the Basin has a longer integral time scale but smaller turbulent diffusivity for single particle dispersion. We also point out that inadequate mean-eddy separation and/or data limitation could result in different conclusions.

C103

Isopycnal floats as platforms for in-situ studies

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It is now well established that isopycnal floats follow density surfaces very closely on all time scales, including those for internal waves. Knowledge of this can be used to study various processes: isopycnal stirring and mixing from in-situ changes in temperature, vorticity conservation from along-track variations in Lagrangian stretching vorticity, the internal wave sea state from pressure, and biologically important parameters such as oxygen.

Lagrangian temperature and depth along an isopycnal, particularly in fronts and eddy fields, reveal pathways of cross-frontal exchange (at various depths) and how fluid parcels move laterally and vertically in growing and decaying meanders. Changes in temperature signal incursions of water with different temperature-salinity properties and thereby indicate lateral stirring and mixing processes. These can occur quite suddenly in fronts, a clear indication of strong lateral shear that increases the contact area between adjacent water masses.

Stretching vorticity or static stability, N2=-g/rho(drho/dz), has been measured by numerous floats deployed in the North Atlantic Current (NAC) study. Floats usually show the expected changes in layer thickness as they down- or upwell in meanders, and in response to flow over topography. One float, caught in an anticyclonic lens, indicated a pycnostad with almost zero stratification implying recent exposure to the atmosphere. Generally speaking, floats evince greater N2 activity in energetic than in quiet regions.

All floats in the ACCE study measured dissolved oxygen along their tracks. Floats that surface due to winter time convection show the oxygen levels rapidly becoming (super-) saturated. In spring as the seasonal thermocline reestablishes itself, a gradual reduction in O2 levels takes places indicative of oxygen utilization. The changes in O2 levels can be quite strong and presumably rather patchy because they can quickly get erased by mixing events.

C104

Tracing the Mediterranean thermohaline circulation as it results from GCM simulations.

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We present results obtained in the context of UE funded TRACMASS project that employs Lagrangian trajectories to investigate the North Atlantic and Mediterranean water mass circulation as they result from GCM numerical simulations. More specifically we will present some example of the results obtained in the study of the Mediterranean thermohaline circulation as the 'section to section' transport stream function, the statistical analysis of the sub basin exit times and the study of the lagrangian renewal time scales versus water ages.

C105

Finite-scale Lyapunov analysis of Lagrangian trajectories from Mediterranean GCM simulations.

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The Finite-Scale Lyapunov Exponents (FSLE) are measured to estimate relative dispersion rates of Lagrangian trajectories integrated off-line from theoutput of a Mediterranean Sea GCM. This diagnostics is used for characterizing both global and local mixing properties of the Mediterranean Sea model surface circulation. One of the main results is that relative dispersion is dominated by mean shear effects up to gyre-scales and indications of chaotic advection, i.e. exponential separation between particles, are present at the meso-scales. An analysis of nine clusters of numerical floats allowed to inspect the spatial scales of anisotropy of the dispersion as well as to observe a standard diffusion behavior in the recirculations. The spatial distribution of the FSLE (I kind) can describe local dispersion properties and identify regions at high or low rates of mixing over an assigned spatial scale. At this regard, we discuss briefly the relation between Lagrangian and Eulerian observables when finite-scale transport properties are concerned. Lagrangian unpredictability source is the sensitivity to both the initial conditions and the uncertainty in the evolution law, e.g. an imperfect knowledge of the velocity field. The so-called FSLE of II kind is used to characterize, for

three different sampling time of the velocity field (daily, monthly and yearly means), the effect of Eulerian time resolution on the accuracy of the Lagrangian trajectory computation.

C106

Can general circulation models be assessed and enhanced with drifter data ?

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(Abstract received 07/31/2000 for session C)

Drifter data from the Gulf of Mexico are used to assess and enhance a primitive equation, general circulation model. The analysis is made in a 450 km by 450 km open subdomain encompassing a warm core Loop Current ring. The model velocity field is compared with position data from four drifters at the drogue depth of 50m using geometrical orthogonal functions (GOFs). An Eulerian velocity field is reconstructed from the model velocity field and drifter velocities. This reconstructed velocity improves the accuracy of numerical trajectories relative to the model field by at least an order of magnitude, as quantified by two Lagrangian error metrics referenced to the real drifter paths. Enhancement of the model velocity field is determined by two tests: the ability of the GOF velocity field to: 1) improve the forecast of drifter positions using only a posteri data and 2) improve the forecast of withheld drifter data.

C107

POP Model Evaluations Using North Atlantic WOCE Drifter Data

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(Abstract received 07/31/2000 for session C)

A 0.1-degree, 40 vertical level North Atlantic configuration of the Los Alamos National Laboratory Parallel Ocean Program (POP) model, forced with 1993-1997 Navy Operational Global Atmospheric Prediction System (NOGAPS) daily wind stresses, is used to address the feasibility of using POP in a future global predictive system. Quantitative model evaluations using data that capture high-frequency (several days to several months) and shorter-scale (10-1000 km) ocean processes are needed to assess model performance. The model's surface circulation is evaluated by calculating Eulerian and Lagrangian statistics from North Atlantic World Ocean Circulation Experiment surface drifter data and co-located model velocities. Since these runs are very computationally intensive, the importance of model resolution is investigated by comparing a third set of statistics obtained from a coarser resolution (0.28-degree, 20 levels) POP simulation.

The Eulerian comparisons show that the mean and variability of the higher resolution run are very realistic while in the coarser resolution model features are inaccurate in places and energy levels are significantly under-represented. Numerical trajectories are computed from the model velocity fields using a fourth-order Runge-Kutta scheme. From these and the observed trajectories diffusivites and Lagrangian time scales are calculated and compared. The time scales from the higher resolution simulation are not statistically different from the observed scales, while those from the coarser resolution run are generally too long. In all, the 0.28-degree simulation is too viscous and has too much ``memory", while the 0.1-degree run more faithfully reproduces the observed surface circulation.

C108

Comparison of Lagrangian data in a high resolution North Atlantic model with in-situ drifter data

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(Abstract received 08/15/2000 for session C)

A model/data comparison was performed between simulated drifters from a high resolution numerical simulation of the North Atlantic and a data set from in-situ surface drifters. The model is a version of the Miami Isopycnic Coordinate Ocean Model, with 1/12 deg horizontal grid spacing, and 16 layers (a bulk mixed layer and 15 isopycnic layers), forced with COADS climatological fields.

The comparison makes use of pseudo-Eulerian statistics such as mean velocity and eddy kinetic energy, and Lagrangian statistics such as integral time scales. Comparisons of eddy kinetic energy and root mean square velocity indicate that the numerical model underestimates the eddy kinetic energy in the Gulf Stream extension and in the ocean interior. In addition, the model Lagrangian time scales are longer in the interior than the in-situ time scales by approximately a factor of two. It is suggested that this is primarily due to the lack of high frequency winds in the model forcing, which causes an

underestimation of the directly forced eddy variability. The mean flow comparison has been performed both qualitatively and quantitatively using James' statistical test. The results indicate that over most of the domain, the differences between model and in-situ estimates are not significant. However, some areas of significant differences exist, close to high energy regions, notably around the Gulf Stream path, which in the model lies slightly north of the observed path, although its strength and structure are well represented overall. Mean currents close to the buffer zones, primarily the Azores Current, also exhibit significant differences between model results and in-situ estimates.

Results of a second North Atlantic numerical simulation forced with ECMWF climatology are discussed in comparison with the COADS forced simulation.

C201

Statistical errors in estimating mean flow from Lagrangian data.

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Lagrangian data are an important component of WOCE, providing extensive sampling in both the horizontal and the vertical. They are often used to estimate ocean mean flows, using the "binning" technique where averaging is performed over certain spatial bins and certain time periods. These "pseudo-Eulerian" estimates are known to be possibly contaminated by biases due to correlations between drifter concentration and velocity (e.g. Davis, 1991).

Here we study statistical errors of pseudo-Eulerian mean flow estimates using synthetic drifter trajectories, computed in a numerical flow from a high resolution MICOM run in the North Atlantic (Garraffo et al., 2000). The full data set is substantially larger than the WOCE requirement, and allows to study the effects of subsampling in space and time. The estimates from Lagrangian data are compared to "true" Eulerian averages over 1 degree square bins. Sampling errors, related to subgrid scale variability and finite sampling, are studied first. Biases effects are then considered, indicating that pseudo-Eulerian estimates tend to underestimate (overestimate) the velocity in the eastern equatorial regime (western boundary currents). An analysis of the results suggest that these biases are primarily due to mesoscale divergence processes resulting in nonzero correlation between instaneous drifter concentration and velocity.

C202

Lagrangian Analysis Techniques to Estimate Adriatic Sea Surface Circulation Statistics

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(Abstract received 07/28/2000 for session C)

The Adriatic Sea surface circulation for the period 1990-1999 is studied using the data of more than 200 satellite-tracked drifters. The spatial structure and the temporal variability of the surface currents, at meso- to seasonal scales, are described in terms of Eulerian and Lagrangian statistics estimated from the low-pass filtered drifter velocities.

Maps of mean currents, subtidal velocity variance and mean kinetic energies were produced using 40-km-diameter circular bins. This averaging scale was chosen as a trade-off between horizontal resolution and statistical accuracy. Bins with a small number of independent observations or a strongly non-uniform seasonal data distribution were rejected to eliminate erroneous statistics. Sampling random and bias errors affecting the mean flow estimates were estimated.

Similar maps were produced for the four seasons of the year to assess the seasonal variability of the surface currents. James' test for the null hypothesis that means are equal was used to compare the mean velocity fields. The mean flow map confirms that the global cyclonic circulation in most of the Adriatic basin is broken into three re-circulation cells in the northern, central and southern sub-basins. Mean velocities in the cyclonic gyres can exceed 25 cm/s in the coastal areas where the velocity variance is also maximum (reaching 500 cm^2 s^-2).

Values near 2 x 10^7 cm^2 s^-1, 2 days and 18 km were obtained for the diffusivity and the Lagrangian integral time and spatial scales in the along-basin direction, respectively. In the across-basin direction, the statistics are typically 50% of the above values.

C203

Entropic Analysis of Lagrangian Mixing at Varying Temporal Resolution

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The entropic analysis of extended system helps to find realistic
models of extended spatiotemporal systems. The analysis is especially powerful in cases where one can coarse-grain the phase space by physical observation and/or assumptions. We extend the coarse graining from the phase space as well to the time domain by applying physically motivated filtering techniques. The entropy is calculated by the powerful method of the exit-times and compared with conventional results. We investigate is a simplified model of the gulf stream with special emphasis of mixing effects between the different gulf stream regions. Possible further applications are mixing between distinct oceanographic regions or the spreading of pollutants in mixing systems.

C204

Advective Transports in Monterey Bay, Part I: HF Radar-Derived Current Fields

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This is the first of three reports that analyze the advective transport in Monterey Bay, California using repeated surface velocity maps from high-frequency (HF) radar systems. In this part, the configuration of the HF radar network is presented. A basic description of the measurement technique is provided along with spatial and temporal coverage statistics dating back to August 1994. Spatial EOF modes of variability are presented that highlight recurring patterns related to variations in the alongcoast (upwelling favorable) wind forcing. These modes can be compared with the boundary influenced basis functions used in Part II (Kirwan et al.). Simple particle trajectories based on nearest velocity advection are presented, which can be compared with the trajectories derived from dynamical systems theory in Part III (Coulliette et al.). In all cases, surface particle advection in this coastal system is seen to be sensitive to the combination of background geostrophic currents, upwelling-related currents and current reversals, and diurnal to seabreeze and tide-driven currents.

C205

Advective Transport in Monterey Bay, Part II: Flow Charactersitics

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This is the second of three reports that analyze the advective transport in Monterey Bay using dynamical systems templates. Here the HF radar data described in Part I (Paduan et al) are projected onto numerically derived basis functions to produce maps of the surface velocity every two hours. Using dynamical systems templates, these maps are used in Part III to delineate transport pathways. The projection is used to fill in data voids, ensure compatability with flow conditions at open and closed boundaries in the analysis domain, and blend disparate data and model output to produce synoptic fields. However, the results reported here are based soley on the HF radar observations described in Part I. There are two types of basis functins. The vorticity basis is streamfunction like and contains all the vertical vorticity. The divergence basis is velocity potential like and contains all the horizontal divergence. In three dimensions, not discussed here, the complete basis set is incompressible. Data from August 1994 and June through August 1999 are compared. The percent variance explained by each mode shows inconsequential differences between the 1994 and 1999 data sets. Spectra of amplitudes from these two periods show strong peaks at one and two cycles per day, indicative of tides and wind forcing. There is also energy at lower frequencies in the vorticity modes. Thus advective transport models in this region must account for both large-scale flow structures and tides.

C206

Advective Transport in Monterey Bay, Part III: Dynamical Systems Analysis

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Early applications of dynamical systems theory to understand transport utilized simple analytic functions to describe the velocity field. More recent applications, such as the one described here, rely instead on large amounts of high-resolution synoptic data obtained through remote sensing. We briefly describe the dynamical systems framework for

Lagrangian transport, but the focus will be on transport in a coastal system (i.e., Monterey Bay) using a velocity field obtained from high frequency (HF) radar measurements. In particular, we study the surface velocity of Monterey Bay obtained from three HF radar antennae at Santa Cruz, Moss Landing and Point Pinos. The surface currents of Monterey Bay are obtained at spatial intervals of approximately 2 km and temporal intervals of approximately 2 hours by interpreting the resonant backscatter in the spectral returns for transmitted frequencies from the HF radar antenna. We will show how dynamical systems theory applies to this data and gives new insight into transport and predictability of transport processes in a coastal system.

C207

Dynamical Systems Approach to Lagrangian Transport: Fluxes and Barriers in a Double Gyre Flow

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We study the influence of eddies detaching from a jet on intergyre transport in a model consisting of a three layer quasigeostrophic flow in a square domain subject to a sinusoidal in space (constant in time) wind stress that leads to the double gyre configuration. We use techniques from dynamical systems theory to study intergyre transport. In particuliar distinguished hyperbolic trajectories (DHT's) along with their stable and unstable manifolds are computed in order to implement the technique of lobe dynamics. An unstable manifold associated with a DHT on the western boundary and a stablemanifold associated with a DHT on the eastern boundary are computed. These manifolds control intergyre transport. The influence of detached eddies on intergyre transport can then be determined by studying their influence on these stable and unstable manifolds. These eddies also have associated DHT's with their own stable and unstable manifolds. These are computed in order to understand their interaction with the unstable and stable manifolds on the boundaries controlling intergyre transport as well as to study the flux between the eddies and the main flow. Bifurcations of the stagnation points associated with the eddies complicate the computation of the DHT's. Special cases of bifurcations are studied and the issue of the existence of a DHT during a bifurcation of stagnation points is outlined.

Section D Abstracts

D101

Reconstructing Basin-Scale Eulerian Velocity Fields from Simulated Drifter Data

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A single layer, reduced gravity, double gyre primitive equation model in a 2000 km by 2000 km square domain is used to test the accuracy and sensitivity of time dependent Eulerian velocity fields reconstructed from numerically generated drifter trajectories and climatology. The goal is to determine how much Lagrangian data is needed to capture the Eulerian velocity field within a specified accuracy. The Eulerian fields are found by projecting, on an analytic set of divergence free basis functions, drifter data launched in the active western half of the basin supplemented by climatology in the eastern domain. The time dependent coefficients are evaluated by least squares minimization and the reconstructed fields are compared to the original model output. We find that the accuracy of the reconstructed fields depends critically on the spatial coverage of the drifter observations. With good spatial coverage, the technique allows accurate Eulerian reconstructions with under 200 drifters deployed in the 1000 km by 1400 km energetic western region. The base reconstruction error, achieved with full observation of the velocity field, ranges from 5% to 30% depending on the number of basis functions. We conclude that with appropriate coverage, drifter data could provide accurate basin scale reconstruction of Eulerian velocity fields.

D102

Mathematical Modeling Experiments to Estimate the Distribution of Tracer and Water Particle Movement

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(Abstract received 08/02/2000 for session D)

Izmir Bay is one of the most polluted estuaries in the whole Mediterranean Sea. Especially the Inner Bay is heavily affected by domestic and industrial loads amounting to ca. 5 million population equivalents. As a result of these loads, strong eutrophication occurs in the inner sections of the Bay, which is temporally anaerobic. The ecologically sensitive approach of the local authorities in the last decade gave rise to a wide variety of monitoring and research studies.

Calibration and validation of the physical component of the model has been completed in 1997. Bryan-Cox-Semtner free surface model (KILLWORTH Model) is used for this study. Water quality model studies have been initiated by the Water and Sewerage Authority in Izmir (IZSU). The main goal of these studies was to produce the necessary details to support the decision mechanisms of IZSU. For this water quality study, again KILLWORTH Model has been used. The reason for this selection is the encouraging recent usage of this model in ecomodeling and the already proven power of the background hydrological component.

The wastewater will be discharged into the Middle Bay from the sea surface after a mechanical treatment first and a secondary treatment later. So, the model experiments are conducted to estimate the distribution of pollutants. In the model the continuous discharge of pollutant is represented as a regular discharge of discrete particles.

D103

Sediment particle transport prediction, based on the Random Walk simulation.

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A three-dimensional mathematical model for the advection, diffusion and sedimentation of the fine-grained suspended particulate matter has been developed. The model is based on the Random Walk simulation (Lagrange-Monte Carlo Method). According to this method, a large number of particles representing a particular amount of mass, is introduced to the flow domain through a source. Their transport and fate is traced with time. Horizontal advection of the particulate matter is controlled by the local fluid velocity. Vertical advection is controlled by the local fluid velocity and the particle settling velocity. Turbulent diffusion is simulated by the random Brownian motion of the particles due to turbulence. The model includes processes like flocculation, settling, deposition and

erosion-resuspension of the cohesive fine grained sediments.

An application is presented for Thermaikos Gulf, North Aegean Sea, where the rivers are the sources of the sediment particles. The model is coupled off-line with the hydrodynamic Princeton Ocean Model. The three-dimensional velocity field is provided to the transport model by a typical one-year simulation of the hydrodynamic model. The seasonal variability of the particle transport is compared to observational data of Suspended Particulate Matter. The importance of the sedimentary processes is assessed by comparing results to the transport of pure water particles.

D104

Predictability of Drifter Trajectories in the Tropical Pacific Ocean

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Predictability of particle motion in the ocean over a time scale of one week is studied using 3 clusters of buoys consisting of 5-10 drifters deployed in the tropical Pacific Ocean. The analysis is conducted by using three techniques with increasing complexity: the center of mass of the cluster, advection by climatological currents, and a new technique, which relies on the assimilation of both velocity and position data from the surrounding drifters into a Markov model for particle motion.

The results indicate that cluster predictability can be characterized using the data density Nd, defined as the number of drifters over an area scaled by the mean diameter of the cluster. The data density Nd decreases along the drifter trajectories due to the tendency of particles to disperse by turbulent fluid motion. In the first regime, which corresponds to the period after the release of drifters in a tight cluster when Nd1 drifter/degree^2, the center of mass and the data assimilation methods perform nearly equally well, and both methods yield very accurate predictions of drifter positions with rms prediction errors less than 15 km up to 7 days. When a cluster starts to disperse, i.e., in the regime where Nd1 drifter/degree^2, the data assimilation technique is the only method that gives accurate results. Finally, when Nd<<1 drifter/degree^2, no method investigated in this study is effective. Uncertainties in the knowledge of initial release positions and the frequency of data assimilation are found to have a strong impact on the prediction accuracy.

D105

Assimilation Experiments with Simulated Drifter Data as Velocity Measurements

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Strategies for assimilation of drifter trajectory data intoa numerical ocean model (Eulerian) are considered. Converting the drifter trajectories into surface-layer velocities seems to be a simple, practical method, which is examined here. Twin experiments are conducted with a 20-km grid, double-gyre circulation model (a 4-layer configuration of Miami Isopycanl Coordinate Ocean Model). The ROIF (reduced-order information filter) implementation of Kalman filter is used for data assimilation. A small number of clusters of tracers are released to simulate drifter trajectories, from which surface velocities are derived for the assimilation runs.Preliminary results indicate that the spatial coverage of the derived velocity measurements is an important limitingfactor in reproducing meso-scale features through assimilation.

D106

Lyapunov Exponents for Stochastic Flows Modeling the Upper Ocean Lagrangian Motion

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Two new stochastic models of the Lagrangian motion in the upper ocean are considered. The first one implies a Brownian motion of individual particles and is not much realistic. However, it allows explicit formulas not only for the classical Lyapunov exponent, but for the finite Lyapunov exponent as well in terms of the velocity variance and space correlation radius.

The second model implies a Langevin equation for a single particle motion as in the classical Thomson-Griffa model. Unlike that model, our apprach yields a mathematically consistent description of the motion of any number of particles. In this case some

asymptotics of the Lyapunov exponent are found as function of the Lagrangian correlation time, the velocity variance, and the space correlation time. The dependence of the Lyapunov exponent on those parameters is investigated by Monte Carlo means for their realistic values.

The problem of Lagrangian trajectory predictability in the ocean is discussed based on the Lyapunov exponent findings.

D107

Relation between Lagrangian Stochastic Models and Equations of Fluid Mechanics

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A general LS model is considered covering motion of any number of particles. The corresponding one-particle motion model includes Markov models of any order as a partial case. In a recent work by R. Mikulevicius and B. Rozovskii , a rigorous derivation of stochastic Navier-Stokes and Euler equations for the corresponding Eulerian velocity was presented. These equations are natural extensions of the classical equation of Fluid Mechanics to the case when the fluid particles are subject to short-time turbulence. The existence and uniquiness conditions for the corresponding Eulerian velocity field were given in terms of the Lagrangian drift and diffusion tensor. In this talk we will discuss how some popular hydrodynamic LS models introduced by different authors (Thomson, Reynolds, Pedrizzetti and Novikov) relate to this general approach. We also discuss the Lagrangian data assimilation problem in context of our findings.

D108

Lagrangian coordinates for ocean data assimilation

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When assimilating Lagrangian data into a regional primitive equation model, Lagrangian coordinates offer two distinct advantages over Eulerian coordinates. First, the positions of the floats are the natural dependent variables of the model. Second, the coordinates facilitate modeling in Lagrangian open domains which, unlike Eulerian open domains, lead to well posed forward and backward problems. These are essential for the construction of efficient inversion algorithms.

Working with the shallow water model, we have determined that forward Lagrangian integrations accurately describe a domain that moves with uniformly rotating flow. For time and space scales of North Atlantic mesoscale variability, the solutions from inviscid Lagrangian integrations are within a few percent of those from inviscid Eulerian integrations for approximately 20 to 30 days. By this time, the turbulent cascade of entrophy to small scales renders the solution meaningless.

Including viscosity in double periodic domains on the flat earth extends the time limit to over a hundred days, for grid Reynolds numbers as large as 5 but not 10. This time limit is entirely satisfactory and flat earth doubly periodic domains will be used in first tests of assimilations of float data over a few months.

Anticipating the need to work eventually in nonperiodic open domains on the spherical earth, it must be conceded that viscosity resolves the ill posedness in principle, but not in practice as discontinuities are replaced with spurious boundary layers. Thus the second attraction of Lagrangian coordinates, namely that they facilitate computation of well posed Lagrangian open boundary problems, remains.

D109

The role of coherent Lagrangian structures in turbulent transport

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(Abstract received 07/31/2000 for session D)

With recent advances in dynamical system theory and Lagragian stochastic (LS) models, it is now possible to address the role of Lagrangian structure in transport and mixing. Observations or modeling result in sampled data of a given flow, thus small features beneath the level of observation or discretization, i.e. sub-grid scale motions, will not be captured. Several authors have explored the use of random walks to ascertain the effect of the sub-grid scale motions in oceanic applications (e.g. Dutkiewicz et al. [1993], Lacorata et al. [1996], Buffoni et al. [1997]). However, these efforts were limited to modeling small-scale turbulence which is both stationary and homogeneous. Much theoretical work has been done recently (from Thomson [1987] to Reynolds [1998]) to overcome these limitations by developing random walks into more general LS models which can simulate the effect of nonstationary and inhomogeneous turbulence. Our work is focused on how to implement a modern LS model in a sub-grid scale context and how to merge it with the lobe dynamics approach, so that a unified framework to transport and mixing is developed which allows us to better understand the roles of coherent Lagrangian structures and turbulent diffusivity, i.e. dynamical systems theory tells us which particles to track, while LS models tell us how to track the particles.

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