Outline

Holiday Inn Key Largo & Marina

Address: 99701 Overseas Highway
Key Largo, Florida
USA 33037
approximately 60 miles south of Miami on US 1 at MileMarker 100,
Ocean side (left).
Telephone: +1-800-THE-KEY-S (Extension 2) or +1-800-843-5397 (local +1-305-451-2121)
Fax: +1-305-451-5592
E-mail: info@holidayinnkeylargo.com
Web page: www.holidayinnkeylargo.com (www.keylargoresorts.net)

Tourist Guides:

www.floridakeys.com	www.see-floridakeys.com
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www.keywest.com	www.key-west.com

Cover art work by Jean Carpenter.

Meeting Announcement

Dear Colleague,

The LAPCOD 2002 meeting will take place in Key Largo, Florida during December 12-16, 2002 (Thursday-Monday).

The purpose of the LAPCOD meeting is to conduct a review of Lagrangian data, present new results on nonlinear aspects of Lagrangian dynamics, and to accelerate future development in predictability and multi-disciplinary aspects, by bringing together different research communities and different analysis. Workshop invitees will include experimentalists and theoreticians involved in data analysis and model development, as well as predictability experts (not necessarily all oceanographers), biologists, meteorologists and ecologists using Lagrangian instruments and approaches. Lagrangian predictability is of great importance for practical application in transport and environmental problems, and we expect that the workshop will facilitate its development through exchanges and collaborations.

We anticipate a total workshop attendance of 50-100 people. The workshop will be structured to encourage collaborations and exchanges of ideas, with 12 minute discussion talks in the morning and poster sessions in the afternoon. Participants are encouraged to present both a short talk and a poster.

Thu:	Observations and biological applications.
Fri:	Theory of dispersion/transport/mixing.
Sat:	A day of interactions via a group social activity.
Sun:	Lagrangian instruments and data analysis techniques.
Mon:	Assimilation of Lagrangian data and predictability of trajectories.

We would also appreciate some talks/posters on a historical review of Lagrangian instruments, turbulent mixing, nonlinear analysis and what have we learned about the mean ocean state and its variability from measurements. If there is sufficient interest, we would like to produce an edited book from this meeting. Presently, we have four proposed chapters and we would love to hear from you, before the meeting, if you would like to submit a chapter.

Feel free to send this announcement to colleagues.

Sincerely,

Annalisa Griffa	RSMAS, University of Miami, Miami, Florida, USA Consiglio Nazionale Ricerche (CNR)/ IOF, La Spezia, Italy
Arthur Mariano	RSMAS, University of Miami, Miami, Florida, USA
Tamay Ozgokmen	RSMAS, University of Miami, Miami, Florida, USA
Enrico Zambianchi	Istituto di Meteorologia e Oceanografia, ItalyDear Colleague,

LAPCOD Meeting Agenda

This meeting is being 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. We ENCOURAGE you to present both a short talk (12 min + 3 min Q/A) in the morning session and a poster with details in the afternoon (This is not a strict requirement, you can do just one or the other).

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

Thursday's session will focus on estimates of first and second-order statistics of velocity, plankton, tracer and otpical properties of the ocean and coastal regime from Lagrangian measurement. We encourage 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.

Friday'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 are encouraged.

Sunday'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 are encouraged.

Monday's session will focus on assimilating Lagrangian data into both Eulerian models and Lagrangian particle models for nowcasts anf 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 are encouraged.

Posters

We encourage people who give oral presentations to present also a poster. Posters can simply be made by hard copies of the presented material or they can serve to show details not given in your morning talk. The purpose of presenting a poster and having an afternoon poster session is to encourage individual communication stimulated by the morning presentation.

Thursday

Observations and biological applications

Moderator: Arthur Mariano, *University of Miami*

8:30 am **Registration**

8:50 am **Welcome to the Key Largo LAPCOD Meeting**
Opening remarks by Arthur Mariano, *University of Miami*

9:00 am A101 Drifter trajectories connecting the coastal seas around South Florida
Elizabeth Williams, Thomas Lee, Villy Kourafalou

9:15 am A102 Absolute transports of the North Atlantic Current from RAFOS floats and historical hydrography
Paula Perez-Brunius, Tom Rossby, Randy Watts

9:30 am A103 The Iceland Basin as an intersection where Labrador Sea and Iceland Scotland Overflow waters meet
W. Zenk, R. H. Kaese, T. J. Mueller

9:45 am A104 Lagrangian measurements in the midlatitude Northeastern North Atlantic
B. Le Cann, A. Bower, K. Speer, P. Richardson, A. Serpette and F. Colas

10:00 am A105 Preliminary Results of the DOLCEVITA Drifter Program in the Northern Adriatic
Laura Ursella, Elena Mauri and Pierre-Marie Poulain

10:15 am A106 The Aegean Sea Pilot Drifter Program
Donald Olson, Villy Kourafalou, William Johns, Geoffrey Samuels and Milena Veneziani

10:30 am **Mid-Morning Break (30 minutes)**

11:00 am A201 Lagrangian observations of the surface circulation of the Tyrrhenian Sea
Pierpaolo Falco, Valentina Lignitto, Pierre-Marie Poulain, Enrico Zambianchi

11:15 am A202 Statistics of Mediterranean eddies
J. Isern-Fontanet, E. Garcia-Ladona, J. Font

11:30 am A203 Warm water motion in the tropical Atlantic from analysis of surface drifter trajectories
Semyon Grodsky, Jim Carton

11:45 am A204 Drifter Observations of the NECC in the Eastern Tropical Pacific
Sean C. Kennan, Pearn P. Niiler, Janet Sprintall

12:00 pm A205 LIDEX Lagrangian Isopycnal Dispersion experiment
T. Rossby, D. Hebert

12:15 pm A206 TBA

12:30 pm **Lunch Break (90 minutes)**

2:00 am A301 Scales and Variability in Larval Dispersal within the IAS
Robert R. Cowen, Claire Paris

2:15 pm A302 Lagrangian Analysis of the Biophysical Dynamics of Fronts
Donald B. Olson

2:30 pm A303 A Lagrangian model for the dispersion of nutrients in coastal waters
M. G. Magaldi, A. M. Doglioli

2:45 pm A304 Lagrangian modeling of diapaused copepods in intermediate to deep layers in the Arabian Sea
N. Idrisi, and M.J. Olascoaga

3:00 pm A305 A stochastic model for the dynamics of a structured population
G. Buffoni, M.G. Mazzocchi, S. Pasquali

3:15 pm A306 A Lagrangian Perspective of Biogeochemical Transformations in River Plumes
Gary L Hitchcock, W. J. Wiseman, Jr., R. Chen

3:30 pm **Thursday Poster Session**

A401 Looping ACCE RAFOS Floats in Eddies
P. L. Richardson, D. Slater, A. S. Bower, H. T. Rossby

A402 Directly-measured mid-depth circulation in the Northeastern North Atlantic Ocean
A.S. Bower, B. Le Cann, T. Rossby, W. Zenk, J. Gould, K. Speer, P.L. Richardson, M.D. Prater,
H.-M. Zhang (presenter: Le Cann)

A403 Mid-depth circulation in the North Atlantic using an inverse model applied to floats derived velocities
Vincent Faure, Kevin G. Speer

6:00 pm **Ice Breaker**

Friday

Theory of dispersion/transport/mixing

Moderator: Annalisa Griffa, *University of Miami, Consiglio Nazionale Ricerche (CNR)/ IOF*

9:00 am B101 Chlorophyll dispersal by eddy-eddy interactions in the Gulf of Mexico
M. Toner, A.D. Kirwan Jr., A.C. Poje, L.H. Kantha, F.E. Muller-Karger, C.K.R.T. Jones

9:15 am B102 Relative dispersion in the Gulf of Mexico
J.H. LaCasce, Carter Ohlmann

9:30 am B103 Drifter trajectories in Florida Straits based on surface velocity fields from East Florida Shelf Coastal Ocean Model
Jerome Fiechter, Christopher N.K. Mooers

9:45 am B104 Near-Surface Transport and Mixing in High Frequency Radar Measurements on the Coast of Florida and Application to Contaminant Release
G. Haller, F. Lekien, A. Mariano, E. Ryan, L. K. Shay

10:00 am B105 On the Horizontal Wavenumber Spectrum of Density in the Near-Surface Layer of the Western Pacific Warm Pool
Alex Soloviev and Roger Lukas

10:15 am B106 Dynamical/Thermodynamical Analysis of Upper-Limb Pathways of the Atlantic Meridional Overturning Circulation Using Synthetic Floats
George R. Halliwell, Jr., Robert H. Weisberg

10:30 am **Mid-Morning Break (30 minutes)**

11:00 am B201 Particle trajectory stability and tracer patchiness in 2D incompressible flows
F. J. Beron-Vera, M. J. Olascoaga and M. G. Brown

11:15 am B202 Oceanic turbulence and stochastic models from Lagrangian data: an overview
Annalisa Griffa, Milena Veneziani

11:30 am B203 Oceanic turbulence and stochastic models from Lagrangian data: results in the North Atlantic Ocean
Milena Veneziani, Annalisa Griffa, Andy Reynolds, Arthur J. Mariano

11:45 am B204 Study of mixing via Lagrangian stochastic models
Leonid I. Piterbarg

12:00 pm B205 Lagrangian Transport and its Implications for Ocean Modeling
C.K.R.T. Jones, K. Ide, L. Kuznetsov

12:15 pm B206 Material transport in the presence of wave-structures
Andy Reynolds

12:30 pm **Lunch Break (90 minutes)**

2:00 pm B301 Surface Transport and Mixing in Monterey Bay: A First Look from Synoptic HF Radar Measurements
B. L. Lipphardt, Jr., A.D. Kirwan, Jr., C. E. Grosch, J. D. Paduan, D. Small, S. Wiggins, K. Ide

2:15 pm B302 Surface Transport and Mixing in Monterey Bay: A Turnstile Based Analysis without Hyperbolicity or Invariant Manifolds
Stephen Wiggins, Des Small

2:30 pm B303 Surface Transport and Mixing in Monterey Bay: Escape Time/Location Analysis
Des Small, Stephen Wiggins

2:45 pm B304 Lagrangian Analysis and Prediction in Monterey Bay Using Finite-time Lyapunov Exponents

of HF Radar Velocity Data: Application to Optimal Release of Contaminants
C. Coulliette, F. Lekien, G. Haller, J. Marsden, J. Paduan

3:00 pm B305 Open-Boundary Modal Analysis: A Complete Functional Basis to Interpolate, Extrapolate and Filter Experimental Eulerian Data
F. Lekien, C. Coulliette, J. Marsden, R. Bank

3:15 pm B306 A Lagrangian stochastic model for dispersion in unsteady inhomogeneous sub-filter scale turbulence
C. Coulliette, A. Reynolds

3:30 pm B307 A new approach to transport in the large-scale ocean circulations
Kayo Ide and Stephen Wiggins

3:45 pm **Friday Poster Session**

Saturday

A day of interactions via a group social activity

Tour Guide: Arthur Mariano, *University of Miami*

10:00 am to 12:00 pm	Glass bottom boat or snorkeling.
2:00 pm to 5:00 pm	Bus ride to Key West.
5:00 pm to 8:00 pm	Sight See/Shop/Drink in Key West.
8:00 pm to 10:30 pm	Group Dinner in Key West.
10:30 pm	Bus leaves Key West.

Sunday

Lagrangian instruments and data analysis techniques

Moderator: Enrico Zambianchi, *Istituto di Meteorologia e Oceanografia*

10:00 am C101 http://OceanCurrents.rsmas.miami.edu
A.J. Mariano, E.H. Ryan and J. Gyory
10:15 am C102 Favorite Trajectories
10:30 am C103 Favorite Trajectories
10:45 am C104 Efficient Navigation and Adaptive Sampling Strategies for Fleets of Autonomous Underwater Gliders
E. Fiorelli, S. Shadden, N.E. Leonard, J.E. Marsden
11:00 am C105 TELEPHOS: A new surface drifter for coastal and lake studies
Vassilis Zervakis, Michalis Ktistakis, Dimitris Georgopoulos and Antonis Kantidakis
(Presented by V. Kourafalou)

11:15 am **Short Break (30 minutes)**

11:45 am C201 Synoptic Comparisons of Numerical Simulations with Drifter Observations of JES Circulation
Inkweon Bang, Christopher N.K. Mooers, Francisco J. Sandoval
12:00 pm C201 Quantitative estimate of inter basin exchanges in the Mediterranean Sea from Lagrangian diagnostics applied to a OGCM
V. Rupolo, D. Iudicone
12:15 pm C203 A Catch-and-Release Drifter that Resolves Characteristic Scales of Coastal Dynamics
Carter Ohlmann, Andy Sybrandy, and Peter Niiler
12:30 pm C204 Mean and variability of the flow from quasi-Lagrangian floats
Claudia Schmid, Elizabeth Johns, Robert L. Molinari, Silvia L. Garzoli

12:45 pm **Lunch Break (90 minutes)**

2:15 pm C301 Surface Wave and Shear Measurements with Surface Drifter
Pierre-Marie Poulain, Davide Deponte and Laura Ursella
2:30 pm C302 Direct Measurements of Water-following Characteristics of CODE Surface Drifters
Pierre-Marie Poulain, Laura Ursella and Fabio Brunetti
2:45 pm C303 Vortex statistics from Eulerian and Lagrangian time-series
Claudia Pasquero, Antonello Provenzale, Jeffrey B. Weiss
3:00 pm C304 Reconstruction of near-surface drifter trajectories in the Pacific Ocean with a hybrid model
Nathan Paldor, Yona Dvorkin, Arthur J Mariano, Tamay Özgökmen, and Edward Ryan
3:15 pm C305 TBA

3:30 pm **Sunday Poster Session**

6:30 pm **Group Dinner at the Holiday Inn**

Monday

Assimilation of Lagrangian data and predictability of trajectories

Moderator: Tamay Özgökmen, *University of Miami*

9:00 am D101 Simple prediction algorithms for the Lagrangian motion
Leonid I. Piterbarg and Tamay M. Özgökmen

9:15 am D102 Lagrangian Predictability, Hyperbolicity, and Optimal Observing Strategies for the Ocean
A.D. Kirwan, Jr., M. Toner, and A.C. Poje

9:30 am D103 Assimilation of drifter observations for the reconstruction of the Eulerian circulation field
Anne Molcard, Leonid I. Piterbarg, Annalisa Griffa, Tamay M. *Özgökmen, and Arthur J. Mariano*

9:45 am D104 Assimilation of drifter observations in primitive equation models of midlatitude ocean circulation
Tamay M. Özgökmen, Anne Molcard, Toshio M. Chin, Leonid I. Piterbarg, and Annalisa Griffa

10:00 am D105 A direct data assimilation method for Lagrangian observations
Kayo Ide, L. Kuznetsov and C.K.R.T. Jones

10:15 am D105 A method for assimilation of Lagrangian tracer measurements
L. Kuznetsov, K. Ide, C.K.R.T. Jones

10:30 am D106 Assimilation of simulated float data into the viscid Lagrangian shallow water model
Jodi L. Mead, Andrew F. Bennett

10:45 am D107 Assimilation of Lagrangian data into an eddy resolving ocean model: the special case of ARGO float displacement data
Michel Assenbaum

11:00 am **Short Break (15 minutes)**

11:15 am **Concluding Remarks**

11:30 am **Monday Poster Session**

12:30 pm **Group discussion on Lagrangian-based experiment during Lunch.**

Session A Abstracts

A101

Drifter trajectories connecting the coastal seas around South Florida

Elizabeth Williams, Thomas Lee, Villy Kourafalou
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(Abstract received 10/30/2002 for session A)

During the last seven years years, over forty nearsurface CODE-type drifters have been released in bimonthly intervals in the Shark River Plume off the southwestern tip of the Florida mainland (25.35 N, 81.23 W). The drifter trajectories show that there is a strong link between the South Florida coastal waters (southwest Florida shelf, Florida Bay, the Florida Keys coastal zone and the Dry Tortugas), as the preferred pathways generally follow a southeastward route through western FloridaBay and the passages between the Keys, then westward along the reef tract to the Tortugas. The route through western Florida Bay is driven primarily by local wind forcing and by a mean sea level slope between the Gulf of Mexico and the Atlantic. The westward route along the reeftract is induced by the prevailing westward component in the local wind and by recirculating gyres and eddies north of the Florida Current. Seasonal variability is also detected, mainly associated with a shift in wind direction from northeasterly in fall and winter to southeasterly in summer. The wind magnitude is also seasonally modified, with strongest winds in the fall and winter seasons, associated with cold front passages. Enhanced stratification during summer and early fall allows a faster response of the drifters to the prevailing offshore component of the wind stress. Consequently, the most direct pathways to the Tortugas occur during the strong northeasterlies in fall, while the longest pathways to the Tortugas occur in summer, due to the southeasterlies that, although weak, effectively cause a northward drift reaching up to 27 N. However, multiple pathways can be seen in any season, reflecting high frequency changes in wind forcing.

Wind and current measurements are employed to compliment the Lagrangian data. It is found that seasonal changes in the regional wind forcing produce seasonal differences in the strength and variability of the currents on the west Florida shelf, as measured by moored Acoustic Doppler Current Profilers (ADCPs). Current amplitudes are greater in winter than in summer, following the enhanced wind stress. There is also a directional seasonal pattern in the measured surface currents which are more southward in the fall, winter, and spring seasons, changing to northward in the summer, due to the shift of summer winds to southeasterly.

A simple multiple regression model was employed to analyze the relationship of the seasonal wind components to velocity components that were computed by drifter trajectories. The analysis took place in the coastal areas which are not directly influenced by strong large-scale currents like those in the Loop Current and in the Straits of Florida. It was found that approximately 70 to 80% of the subtidal variance of drifter derived currents on the southwest Florida shelf and western Florida Bay is due to local wind forcing.

A102

Absolute transports of the North Atlantic Current from RAFOS floats and historical hydrography

Paula Perez-Brunius, Tom Rossby, Randy Watts
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(Abstract received 09/29/2002 for session A)

The North Atlantic Current (NAC)- Subpolar Front (SPF) current system serves as a conduit of warm salty waters into the northern North Atlantic. It is the upper limb of the thermohaline circulation of the Atlantic ocean, and plays a crucial role in the moderation of European Climate. Its transport and corresponding heat fluxes remain uncertain, mainly because the structure of the system is not well known. We estimate the mean absolute transports of mass and temperature (top 1000 db) for the NAC-SPF region, using a new method that combines isopycnal RAFOS float data with Gravest Empirical Mode (GEM) projections of historical hydrography. The mean absolute transport potential field shows a NAC-SPF ``pipe", defined by two bounding transport potential contours. This pipe transports 15.0±3.1 Sv (top 1000 db) from the subtropics into the eastern subpolar North Atlantic. The northward flowing NAC follows a distinct meandering path, with no evidence of permanent branches peeling off the current before reaching the Northwest Corner. As the current enters the Northwest Corner, it appears to split into two branches, which together constitute the eastward

flowing SPF. The two branches converge to cross the Mid-Atlantic Ridge above the Charlie-Gibbs and Faraday Fracture Zones. We calculate the absolute transport of temperature (top 1000 db) across seven transects crossing the NAC-SPF ``pipe''. Since mass is conserved in the pipe, changes in the temperature transports are due to lateral exchange and mixing across the pipe's side walls, and to air-sea fluxes across the surface of the pipe. The NAC-SPF current loses 0.27±0.06 PW on its transit through the region. This loss is much larger than the corresponding heat lost to the atmosphere. We conclude that cross-frontal exchange induced by the steep meanders of the northward flowing NAC is the main mechanism by which heat is lost along the current. (Detailed description of the float-GEM method presented in poster session).

A103

The Iceland Basin as an intersection where Labrador Sea and Iceland Scotland Overflow waters meet

W Zenk, R H Kaese, T J Mueller
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(Abstract received 10/15/2002 for session A)

At intermediate depths of the Iceland Basin low-salinity Labrador Sea water encounters cold, slightly more saline watermasses that have passed the sills between East Iceland and Scotland. The resulting watermass transformation was subject of intensive studies in Kiel during the past five years. RAFOS floats belong to the prime instrumentation to reveal directly circulation patterns in the eastern part of the subpolar gyre system. We present flow paths from the interior and the flanks of the Iceland Basin demonstrating a basin-wide intermediate cyclonic gyre with distinct distributions of mean and eddy kinetic energies. Topographic control prevails along the Reykjanes Ridge. To our surprise we found persistent flow channels for entrained Island Scotland Overflow water (ISOW) at Bight Fracture Zone (~57° N), some 450 km farther to the north then previously assumed. These additional outlets seem to play a significant role in the balance of the main export gateway for ISOW, i.e. the Charlie Gibbs Fracture Zone (52°N).

A104

Lagrangian measurements in the midlatitude Northeastern North Atlantic

B. Le Cann[(1)], A. Bower[(2)], K. Speer[(3)], P. Richardson[(2)], A. Serpette[(4)] and F. Colas[(1)]
[(1)]CNRS (Brest, France), [(2)]WHOI (Woods Hole, USA), [(3)]FSU (Tallahassee, USA), [(4)]SHOM (Brest, France)
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(Abstract received for session A)

During the past decade, several Lagrangian acoustic float experiments took place in the Northeastern North Atlantic. These were aimed at the study of the characteristics of the circulation of the major watermasses of the region, including the Mediterranean Water (MW: AMUSE, ACCE and ARCANE experiments), the North Atlantic Central Water (NACW: ARCANE and POMME experiments) and the Labrador Sea Water (LSW: EUROFLOAT and SFB experiments). The collected datasets are under analysis, and zero-order fields have been derived (Bower et al, 2002; poster to be presented). We present here selected results from these experiments to depict the vertical structure and evolution mesoscale features in the intergyre area of the Northeastern North Atlantic. We will notably show new results related to: - "Northern Meddies": These are recently discovered (Paillet et al, 1999, 2002) varieties of the Meddies commonly found south of 40°N. They exhibit different characteristics and examples of generation, displacements and other behaviours (such as collision with seamounts) will be shown. - "Central Water Eddies": These eddies are seen to be more robust than previously anticipated, and examples of long-lived anticyclones will be presented. These eddies are seen to interact, through merging, or, if the eddies are at different levels, by coming into vertical alignment, and also via baroclinic dipole formation. Deep topography plays an important role in eddy displacements and some effects will be shown.

A105

Preliminary Results of the DOLCEVITA Drifter Program in the Northern Adriatic

Laura Ursella, Elena Mauri and Pierre-Marie Poulain
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(Abstract received 10/23/2002 for session A)

As part of the ONR-sponsored DOLCEVITA program 32 CODE surface drifters were deployed in the Northern Adriatic from NRV Alliance between 21 September and 3 October 2002. These deployments represent the beginning of the monitoring of the surface circulation and sea surface temperature in the Northern Adriatic using more than

120 drifters and extending until the end of 2003. The main scientific objective of the DOLCEVITA program is to quantify the kinematic and dynamic properties of the mesoscale circulation in the Northern Adriatic and study the effects of forcing by winds and river run-offs. Two versions of the CODE drifters were used, the standard type with Argos telemetry and positioning (12 units) and the same drifter fitted with a GPS receiver (20 units). Position sampling with the GPS was programmed at 0.5 hour or hourly intervals. The majority of the drifters were deployed in triplets for which the nearest distance between the drifters was less than 10 km. The deployment locations were selected using the results of statistical simulations in which the goal was to maximize the coverage throughout the basin with the constraint that deployments had to be along specific survey transects. Some locations were changed prior to the releases in order to sample more efficiently interesting mesoscale features seen in satellite images and hydrographic data. The statistical model used to simulate drifter trajectories and to optimize the drifter release strategy was a random flight model based on the statistics (mean circulation, eddy variability and Lagrangian time scale) computed with all historical drifter data in the Northern Adriatic (spanning 1990-1999). Graphical summaries of the data (total drifter population vs time, drifter tracks, etc.) and preliminary surface circulation maps (mean and variability) are presented and discussed. Drifter tramectory segments are overlaid on selected satellite images (sea surface temperature and surface chlorophyll concentration) to illustrate the spatial structures and their evolution.

A106

The Aegean Sea Pilot Drifter Program

Donald Olson, Villy Kourafalou, William Johns, Geoffrey Samuels and Milena Veneziani
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(Abstract received 10/29/2002 for session A)

A pilot program to study the circulation in the Aegean Sea using Global Positioning surface drifters is currently underway in cooperation with the Greek National Center for Marine Research and the University of Athens. Thirty drifters have been launched in the northern Aegean starting in March 2002. The purpose of this presentation is to provide a first overview of the data set collected as of late September 2002.

The major features described in the data set are the mesoscale field in the region which is dominated by eddies trapped within the deep subbasins and a coastal jet along the western side of the Aegean. These circulations interact strongly with the numerous islands and gulfs. In the northern basin there is a drift along the coast where drifters are drawn into the elongated gulfs. Two cases of current bifurcations along coasts are visualized by the array. The first of these involves drifters moving into a gulf versus being entrained into the coastal flow that takes them southward along the length of Greece. The southern part of the Chios Basin is dominated by a large cyclonic circulation. The data suggest inflow to the Aegean along the eastern margin and outflow through the Cyclades islands focused in the west.

A201

Lagrangian observations of the surface circulation of the Tyrrhenian Sea (West Mediterranean)

Pierpaolo Falco[(1)], Valentina Lignitto[(1)], Pierre-Marie Poulain[(2)], Enrico Zambianchi[(1)]
[(1)]"Parthenope" University, Napoli, Italy, [(2)]Ist. Naz. O.G.S., Trieste, Italy
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(Abstract received 10/31/2002 for session A)

The circulation in the Tyrrhenian Sea, a sub-basin of the Western Mediterranean, is not yet very well understood. It is believed that typically the surface current field consists of a basin-scale cyclonic gyre in the southern sector of the basin, while the northern area is characterized by a seasonally modulated wind-induced anticyclonic gyre. We present results of the first year of lagrangian observations of the surface circulation in the Tyrrhenian sea by means of CODE drifters. Since December 2001, instruments have been deployed every six months along the route Naples (East Tyrrhenian Sea) to Palermo (Sicily, South Tyrrhenian Sea) and in October 2002 three-monthly deployments along the route Naples to Cagliari (Sardinia, West Tyrrhenian Sea) started, thanks to the cooperation of the Italian shipping company Tirrrenia. The total number of instruments deployed so far amounts to 30, with a few early failures. The preliminary analysis shows interesting and somehow unexpected results. The drifter trajectories reveal a high variability of the south Tyrrhenian circulation, mostly in the central sector where the mean flow is not very well defined due to a relatively strong eddy activity. Most of the drifters deployed along the Naples-Palermo route get trapped in the southeastern portion of the Tyrrhenian, which leads us to reconsider previous estimates of the

residence time of surface waters in the basin. Along the Italian cost the mean flow is stronger and the drifters follow the expected pattern. The recently started three-monthly deployments will allow to investigate the basin wide circulation with respect also to the inflow and outflow patterns in the Sardinia and Corsica Channel, which rules the renewal of the water in the Tyrrhenian Sea.

A202

Statistics of Mediterranean eddies

J. Isern-Fontanet, E. Garcia-Ladona, J. Font
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(Abstract received 09/23/2002 for session A)

The precise definition of eddy cores in terms of the Okubo-Weiss parameter allows to identify and build a census of eddies in the Mediterranean sea from altimetric maps for the period October 1992-October 1999. The analysis of the properties of these eddies suggests that a distinction between 'weak' and 'strong' eddies can be done in terms of the minimum value of the Okubo-Weiss parameter reached inside an eddy core. The analysis of sizes of the observed structures suggests that 'strong' eddies can be roughly identified with mesoscale eddies. With this criterion to classify eddies it is possible to systematically obtain their trajectories. Results show that Mediterranean eddies are mainly located in the Algerian Basin and the Levantine Basin as suggested by AVHRR images. For the first time a precise picture of the Mediterranean eddy paths has been obtained. The associated velocity P.D.F derived from altimetry also shows characteristic patterns due to the presence of eddies.

A203

Warm water motion in the tropical Atlantic from analysis of surface drifter trajectories

Semyon Grodsky, Jim Carton
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(Abstract received 09/24/2002 for session A)

Subtropical cells connect subduction zones of the eastern subtropics of both hemispheres to the equatorial current systems via equatorward flow in the thermocline. Some of this thermocline water is converted back into warm near-surface water in the eastern equatorial cold tongue from whence it is then exported poleward. Here we examine the export pathways from the cold tongue in the Atlantic based on recently available near-surface drifter data. We find that, similar to its Pacific counterpart, water upwelled in the Atlantic cold tongue follows multiple pathways back into the subtropics, but not directly to the subduction zones. Thus the subtropical cells are open to extensive influence from, and exchange with, the subtropical and midlatitude ocean.

The talk is organized in the following way. First we identify the spatial structure and timing of the entrainment of cool subthermocline water in the equatorial Atlantic mixed layer. Then we consider the drifter trajectories crossing through the cold tongue during the cold tongue season. It will turn out that the pathways taken by the drifters are determined by where they originate within the cold tongue. Finally we explore the sensitivity of pathways to point of origin using the gridded velocity analysis.

This study is based on five data sets: 15m-drogued drifter velocity and position, ocean mixed layer depth, and a gridded velocity analysis, itself resulting from drifter data, climatological surface velocity from historical ship drifts, altimeter sea level, and scatterometer winds.

Our analysis uses 55 drifter trajectories within the 15°S - 30°N band, obtained from the WOCE/TOGA archive at the NOAA/AOML, that pass within the rectangular domain 4°S-2°N and 30°W-0°E during the cold tongue seasons of boreal summer and fall (June-November) when SSTs are low and entrainment is strong. Becauseof limitations on the number and coverage of surface drifters, we supplement our velocity discussion using a multivariate optimal interpolation analysis of climatological seasonal near-surface currents on a 3x2 grid following. The analysis combines Eulerian velocities obtained from the drifter tracks with near-surface pressure variations based on TOPEX/POSEIDON altimetry and monthly scatterometer winds, which together provide information on the geostrophic and ageostrophic components of current.

A204

Drifter Observations of the NECC in the Eastern Tropical Pacific

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(Abstract received 11/01/2002 for session A)

Drifter observations of the North Equatorial Countercurrent in the eastern Pacific reveal that the current has a strong seasonal cycle of amplitude and

flow direction, with maximum eastward speeds occurring in June an July. The current is also narrower than can be inferred using climatological hydrography - so much so, that the meridional curvature of the zonal velocity is comparable to BETA - the planetary vorticity gradient. Taken together, these observations suggest that a revision of Sverdrup's vorticity theory for the NECC may be warranted.

A205

LIDEX ˆ Lagrangian Isopycnal Dispersion experiment

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(Abstract received 10/30/2002 for session A)

Mixing in the ocean has always been separated into two components: diapycnal and isopycnal. In the last few years significant progress has been made to determine the diapycnal mixing in the ocean interior, and the processes responsible for diapycnal exchange are known. However, the stirring and mixing of water along isopycnals is poorly understood and even the use of the terms stirring and mixing depends upon the horizontal scales that are being resolved, i.e. both process and measurement dependent.

We are preparing a field program to investigate the processes and dynamics of dispersion on isopycnal surfaces on scales from kilometers to hundreds of kilometers. Next Spring (2003) we plan to deploy clusters of isopycnal RAFOS floats on two density surfaces in the low-oxygen tongue off West Africa. Thetrajectories of the floats will allow absolute and relative dispersion rates to be determined. Higher-order statistics, such as strain and vorticity, can also be obtained from the clusters of floats.

The low-O2 waters off West Africa at ~10°N results originate in the area of strong upwelling and high biological activity at the coast. From hydrographic surveys it appears that the low-O2 water is advected westward from the upwelling sites, but little is known about the mean circulation in the area. The mean flow of the floats can answer this.

In this talk we review and discuss the float deployment strategy. The reason is that we know so little about the expected isopycnal relative dispersion. We are going to great lengths to put the floats on the same isopycnal so that vertical shear cannot corrupt the interpretation of the results. We plan to deploy the floats in clusters to study their dispersion. But how large should the clusters be, pairs, triplets, groups of ten? This is the question wed like to review.

A301

Scales and Variability in Larval Dispersal within the IAS

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(Abstract received 10/30/2002 for session A)

Early models and evidence from genetics suggested 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 sustain ecologically marine populations. We build on earlier model results to examine the probability of larval dispersal to downstream islands within different regions of the Caribbean at varying distances from source populations . Our modeling approach is based on a coupled biophysical model incorporating a high-resolution ocean circulation model (MICOM), a Lagrangian scheme with larval sub-grid turbulent motion, larval sensory capabilities, and the availability of settlement habitat. Special interest is given to parameterization of the eddy component of the Lagrangian flow field (R-K integration, K, TL). Through sequential runs we estimate the likelihood of particular circulation events transporting large numbers of larvae to within a 9 and 18 km radii of downstream populations. We incorporate realistic larval behavior, mortality estimates, and production variability into our models. Sensitivity analysis on the onset of the active behavior in larval fish is also presented. Our results are consistent with the hypothesis that marine populations must rely on mechanisms enhancing self-recruitment rather than depend on distant 'source' populations.

A302

Lagrangian Analysis of the Biophysical Dynamics of Fronts

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(Abstract received 09/09/2002 for session A)

The application of both Lagrangian models and observations to the problem of understanding the dynamics of oceanic fronts and their role in setting up

marine habitat is reviewed. From the observational perspective surface drifter experiments in the Pacific (Kuroshio and California Current), the Indian Ocean, South Atlantic and Gulf Stream are used to compare these different ecosystems. These observations are used to consider larval dispersal in both pelagic and meroplanktonic organisms. Applications range from understanding the distribution of zooplankton, dispersal of reef organisms across ocean basins, and the spawning of large pelagics. Practical aspects of simulation of larval drift and the inclusion of swimming behavior are discussed. The discussion will conclude with a consideration of the problem of understanding populations that are structured in terms of age and past history. Here the Lagrangian frame is the only feasible one to use in a biological model. Examples of structured models of both individual organisms and subpopulations will be given.

A303

A Lagrangian model for the dispersion of nutrients in coastal waters

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(Abstract received 10/28/2002 for session A)

A Lagrangian single particle model, LAMP3D (Lagrangian Assessment Marine Pollution three-dimensional model) aimed to study the dispersion of nutrients in coastal waters is presented. The purely random approximation is adopted, obtaining a random walk model. The well-known POM (Princeton Ocean Model) [Mellor, 1998] in barotropic approximation provides the depth averaged current velocity. From this field an Ekman transport based submodel embedded in the LAMP3D code is used to provide a simple parameterization of the action of the three-dimensional deterministic velocity field.

An application of the coupled model POM-LAMP3D to study the dispersion of wastes coming from a marine fish farm in the Ligurian Sea is presented. Estimates of the regional dispersion patterns of nitrogen, phosphorus and organic carbon was calculated using a three dimensional grid and compared to in situ experimental data. Result of the simulations clearly showed as dissolved particles tend to spread rapidly and undergoes rapid dilution depending on dominant wind and surface currents direction. In contrast sedimentable particles remain mainly confined in the fish farm area and readily sink to the bottom sediment.

A304

Lagrangian modeling of diapaused copepods in intermediate to deep layers in the Arabian Sea

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In this study, we track trajectories of Lagrangian particles in different isopycnal layers within MICOM fields of the regional domain of the Arabian Sea. The purpose of this modeling exercise is to determine the distributional patterns and fate of individual particles over space and time. We show the relative connectedness among three key upwelling areas in the Arabian Sea: the Gulf of Aden, the Omani coastal waters, and the Somali coastal waters, which are the locations the modeled copepods enter diapause (hibernation). Since the Lagrangian particles represent biological entities, biological dynamics in the form of metabolism and behavior are coded for each individual particle to simulate successful emergence from the diapause state. The general modeling concepts we present are similar to the model of C. Paris and R. Cowen with respect to connectivity among regions of biological activity, though the specific hypotheses contrast in terms of life history strategies adopted by differing biological populations.

A305

A stochastic model for the dynamics of a structured population

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A modelling strategy for the dynamics of a single species of a structured population is proposed. It is based on a stochastic model describing the life history of an individual. The life history of an individual is assumed completely determined by the biological processes of development, reproduction and mortality. The dynamics of the overall population is obtained by the time evolution of the life histories of its individuals. An application to the dynamics of a species of copepods, in different environments, is presented.

A306

A Lagrangian Perspective of Biogeochemical Transformations in River Plumes.

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(Abstract received 11/11/2002 for session A)

River plumes are highly dynamic environments in which terrestrial materials are discharged to the coastal ocean. Large rivers, such as the Amazon, Orinoco, and Mississippi, deliver significant quantities of dissolved inorganic nutrients and terrestrial organic matter to the coastal zone. Transformations of these materials directly influence the magnitude of coastal productivity and influence the photic environment. The shallow depth of many river plumes, in combination with their rapid response to forcing by winds and currents, complicate studies of transformations of dissolved and particulate matter in these dynamic environments. Lagrangian studies of property distributions in river plumes provide one means of identifying processes that regulate the distribution of dissolved inorganic nutrients and Chromophoric Dissolved Organic Matter (CDOM). We have conducted a series of observations in the Mississippi River plume in which the spatial distribution of nutrients and CDOM were mapped while following surface drifters. In all cases, concentrations of dissolved materials in the river plume decrease in a quasi-linear manner with time. These observations argue for physical dilution as a primary mechanism controlling the initial distribution of dissolved materials in this plume. Convergent surface fronts at the edge of the plume appear to be the primary site where biological and other biogeochemical processes transform dissolved and particulate matter as river waters are mixed with ambient shelf water.

Posters Only Section

A401

Looping ACCE RAFOS Floats in Eddies

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ACCE RAFOS float trajectories near the 27.5 density level were analyzed to investigate discrete eddies in the northern North Atlantic with the objective of determining their geographical distribution and characteristics. Floats that made two or more consecutive loops in the same direction (loopers) were considered to have been in an eddy. Overall 16% (25 float years) of the float data were in loopers. One hundred eight loopers were identified in 96 different eddies. Roughly half of the eddies were cyclonic (49%) and half were anticyclonic (51%), although the percentages varied in different regions. Some eddies were stationary for long times (over a year) and others clearly translated, often in the direction of the general circulation as observed by non-looping floats. Several floats were trapped in eddies just upstream (west) of the Charlie Gibbs (52°) and Faraday (50°N) Fracture Zones which seem to be preferred routes for flow crossing the mid-Atlantic Ridge. Six floats looped in five anticyclones which translated southwestward away from the eastern boundary near the Goban Spur near 47°N-50°N. These could have been weak Meddies forming from remnants of warm salty Med Water advected northward along the eastern boundary.

A402

Directly-measured mid-depth circulation in the Northeastern North Atlantic Ocean

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As part of a large international effort to directly observe the circulation throughout the subpolar North Atlantic Ocean, several research groups from the U.S., the U.K., Germany and France collaborated in a major initiative to measure the absolute velocity at two levels in the northeastern North Atlantic using acoustically-tracked subsurface floats. The northeastern North Atlantic is important to the thermohaline circulation as this is where warm subtropical water is transported to high latitudes. A total of 223 float tracks, representing 328 float-years of data, were combined to generate maps of mean absolute velocity and eddy kinetic energy at the Thermocline and Labrador Sea Water levels. We find that most of the mean flow transported northward by the North Atlantic Current at the thermocline level recirculated within the subpolar region, and relatively little entered Rockall Trough or the Nordic Seas. Saline Mediterranean Water reached high latitudes

not by continuous, broad-scale, mean advection along the eastern boundary as previously described, but by a combination of narrow slope currents and mixing processes. At the Labrador Sea Water level, a strong, topographically-constrained current associated with the overflow of dense water from the Norwegian Sea flowed around the northwestern Iceland Basin along the continental slope and Reykjanes Ridge, and closed counterclockwise recirculations existed adjacent to this boundary current. At both levels, currents crossed the Mid-Atlantic Ridge, eastbound and westbound, preferentially over deep gaps in the ridge. The latter result demonstrates that seafloor topography can constrain even upper ocean circulation patterns, possibly limiting the oceans response to climate change.

A403

Mid-depth circulation in the North Atlantic using an inverse model applied to floats derived velocities

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An inverse model is used to map the Eulerian velocity field from a variety of drifters in the North Atlantic. The sources include Palace floats at 1500 db, Marvor floats at 1750 db, Arcane and SFB floats at 1500 db. Other constraints are used as well, derived from fixed current meters in boundary currents. The proposed technique is to average all the velocity measurements into regular boxes which are used to set the model constraints. 2-D mass conservation and `topographic steering' are included in the model in order to generate a smooth stream function along with error estimates. The problem of the choice of noise and assumed horizontal divergence of flow arises as well as choices of the boundary conditions. The results are compared to standard objective analysis technique.

Section B Abstracts

B101

Chlorophyll dispersal by eddy-eddy interactions in the Gulf of Mexico

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A Lagrangian analysis of the transport and dispersal patterns indicated by chlorophyll plumes observed in satellite-derived ocean color images was conducted in the context of a data-assimilating model of the Gulf of Mexico. The interaction between cyclonic and anticyclonic eddies, which are pervasive in the Gulf, played an important role in the transport of chlorophyll-rich shelf water into open waters. In some cases such transport extended across wide areas of the Gulf and delivered biological material to other shelf regions. Such shelf-to-shelf transport was clear between the Yucatan and South Florida shelf, where material was transported in a thin strip along the north wall of the Loop Current after an eddy-shedding event. Another event associated with a cyclone/anticyclone pair at the Louisiana shelf break transported material between the Louisiana Shelf and the northern Yucatan Peninsula. Advective pathways developed from the model align remarkably well with the observed chlorophyll plumes indicating the importance of advective transport by coherent features in shaping plume formation and evolution.

B102

Relative dispersion in the Gulf of Mexico

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We examine multiple particle statistics from surface drifters deployed as part of the SCULP program in the northern Gulf of Mexico. The results suggest two dispersion regimes: one in which particles separate exponentially in time for scales less than the deformation radius and one at larger scales in which particle separations increase with a power law dependence on time. In terms of 2-D turbulence, the first regime is consistent with a local enstrophy cascade and the second with an inverse energy cascade. Both two and three particle statistics are considered.

B103

Drifter trajectories in Florida Straits based on surface velocity fields from East Florida Shelf Coastal Ocean Model

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The velocity fields from a 3-D ocean model of the East Florida Shelf are used to simulate surface drifter trajectories in the Straits of Florida. The model (POM with curvilinear grid, 2-6km horizontal resolution, 25 sigma levels) is being implemented within the SEA-COOS program and is designed to provide real-time, high-resolution ocean data in its regional domain. While still at a developmental stage, the results demonstrate interesting potential to study synoptic and mesoscale features associated with the Florida Current meanders and frontal eddies. The ability to predict particle trajectories, both at the surface and near the bottom, also has direct implications for ecosystem modeling in the Florida Keys, namely to investigate dispersal and recruitment of larvae along the reef tract.

B104

Near-Surface Transport and Mixing in High Frequency Radar Measurements on the Coast of Florida and Application to Contaminant Release

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(Abstract received 11/01/2002 for session B)

We describe a dynamical systems framework for Lagrangian transport in time-chaotic flows. In particular, we will show how dynamical systems theory can now be utilized in the context of real-world problems, such as those derived from the remote sensing observations or the output of a large-scale numerical model. We will illustrate these methods with a study of fluid transport near the Atlantic coast of Florida using a velocity field observed experimentally from very high frequency (VHF) radar measurements. We show that modern remote sensing techniques and recent development in dynamical systems theory can be used to analyze and predict the Lagrangian behavior in this region. If the contaminants are released at a non-optimal time, the

contaminants will be trapped near the coastline by a repelling material line, which is a barrier to transport. If the contaminants are released at an optimal time, chosen when the attachment point of the stable manifold drifts below the release site, the contaminants are caught in the Northern current and carried quickly out of the domain. We used this procedure to explore the use of a small holding tank and compare different contaminant density reduction possibilities in this Florida coastal area.

B105

On the Horizontal Wavenumber Spectrum of Density in the Near-Surface Layer of the Western Pacific Warm Pool

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(Abstract received 09/13/2002 for session B)

The near-surface temperature, salinity, and density fields in the western equatorial Pacific warm pool have a remarkable degree of spatial inhomogeneity. Convective rains produce surface "puddles" containing salinity and density anomalies. These puddles evolve due to interaction with their environment and with each other, producing a variety of spatial scales. This process can be described by a nonlinear advection-diffusion equation. The analysis of this equation allows us to hypothesize the existence of an equilibrium wavenumber range, in which the 1-D spectrum of horizontal density inhomogeneities is given by a formula, where k is the horizontal wavenumber, r is the near-surface water density, and c a dimensionless coefficient. For horizontal wavelengths less than 16 km, the thermosalinograph data from the R/V Le Noroit COARE sections from December 1992 through March 1993 demonstrate good agreement with the theoretical, "k-3" law. A similar "k-3" sub-range is also observed in both the temperature and salinity spectra. However, the salinity contribution to the horizontal density inhomogeneity exceeds the temperature contribution approximately by a factor of 2. The constraints imposed on the warm pool system by these statistical relationships may reduce the number of independent variables in the analysis of the coupled ocean-atmosphere warm pool system, which may be exploited to improve the simulation of the ENSO cycle.

B106

Dynamical/Thermodynamical Analysis of Upper-Limb Pathways of the Atlantic Meridional Overturning Circulation Using Synthetic Floats

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Synthetic floats are released in an ocean model (HYCOM) to study three-dimensional fluid pathways followed by the upper limb of the meridional overturning circulation in the tropical/subtropical Atlantic. An analysis of 7200 floats released in the Southern Hemisphere is performed to demonstrate the importance of, and to quantify dynamical and thermodynamical processes that control, fluid paths extending into the interior subtropical North Atlantic. Vorticity constraints force upper limb water to approach the equator from the south within a predominantly inertial western boundary layer, and then require equatorial processes (inertial boundary layer dynamics, upwelling, heating) to reset water properties and permit the fluid to cross the equator. This typically requires eastward retroflection into the Equatorial Undercurrent. After upwelling at the equator, fluid either advects northward into the interior or westward along the equator to the western boundary. The latter fluid turns northward in a predominantly frictional western boundary (Munk) layer. The generation of negative relative vorticity then breaks the boundary layer constraints and permits retroflection of a substantial fraction of this fluid into the eastward NECC near 5°N from late spring through fall. Much of this fluid advects northward in the Ekman wind drift during the subsequent winter to the southern subtropical gyre, being governed by surface boundary layer dynamics en-route. There the fluid subducts and advects southwestward, governed by layered thermocline dynamics with superimposed time dependent planetary wave variability, eventually entering the westward NEC into the Caribbean Sea. It is necessary to use Lagrangian floats advected by all three velocity components to properly track upper-limb pathways.

B201

Particle trajectory stability and tracer patchiness in 2D incompressible flows

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Particle motion is considered in 2D incompressible flows consisting of a steady background on which a

wave-like perturbation is superimposed. A dynamical systems point of view that exploits the action-angle formalism is adopted. It is argued and demonstrated numerically that for a large class of problems one expects to observe a mixed phase space, i.e., the occurrence of 'regular islands' in an otherwise 'chaotic sea.' This leads to patchiness in the evolution of passive tracer distributions. Also, it is argued and demonstrated numerically that particle trajectory stability is largely controlled by the background flow: trajectory instability, quantified by various measures of the 'degree of chaos,' increases with increasing I|dw/dI| where I is the action and w(I) is the angular frequency of the trajectory in the background flow.

B202

Oceanic turbulence and stochastic models from Lagrangian data: an overview

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(Abstract received 10/10/2002 for session A)

Lagrangian data are especially suitable to study the properties of mesoscale turbulent transport. A general framework to interpret and parameterize turbulent results is provided by particle stochastic models. Previous studies on Lagrangian data (e.g. Falco et al., 200; Bauer et al., 2002) show that off-equatorial flows away from strongly sheared mean currents can be approximated using a simple linear stochastic model, 1-dimensional and of 1-order. This implies that the turbulent flow is mostly diffusive and coherent structures do not play a major role.

The picture changes significantly when highly sheared regions are considered. Here, sub and super diffusive behaviors are present, and coherent vortices are expected to play an important role. A number of different linear stochastic models have been recently proposed in the literature (e.g. Berloff and Mc Williams, 2002; Reynolds, 2002) to reproduce these behaviors. They include higher order 1-dimensional models, and 2-dimensional models with spin. Their statistical properties and relative differences are discussed, in terms of trajectories, autocovariances and cross-covariances of velocity and acceleration.

B203

Oceanic turbulence and stochastic models from Lagrangian data: results in the North Atlantic Ocean

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The historical data set provided by 700 m acoustically-tracked floats (e.g. Owens, 1991) is analyzed in different regions of the north-western Atlantic Ocean. The goal is to characterize the main properties of mesoscale turbulence and to explore Lagrangian stochastic models capable of describing them. In the Gulf Stream extension and recirculation, the data results show significant oscillation time scales and oscillatory patterns both in the velocity autocovariance and crosscovariance functions. They are indicative of sub and super diffusive behaviors. The results also suggest a bimodal distribution of particle trajectories, a number of them being trapped inside highly energetic eddies (loopers), while the rest of the floats experience a poor looping behavior (no-loopers) (Richardson, 1991).

The data statistics are compared with statistics from different stochastic models. A 1-order model with spin is selected, which describes correctly the main observed features. The model couples the two velocity components through a 'spin' parameter, and it is therefore able to represent rotating coherent structures such as vortices and mesoscale eddies. The spin distribution is found to be approximately bimodal, with zero spin for the no-loopers and finite spin for the loopers. The observed super diffusive pattern results from the superposition of the two populations.

B204

Study of mixing via Lagrangian stochastic models

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(Abstract received 09/27/2002 for session B)

The traditional approach to transport in stochastic flows is based on the Fokker-Planck equation which describes merely evolution of the statistical moments of a passive scalar (tracer). To compare theoretical conclusions with observations it is much more important to have description of the tracer realizations rather than its statistics. Lagrangian stochastic models allow us to conclude on the tracer realization behavior. We illustrate that by two examples. The first one addresses the initially linearly distributed tracer in a Brownian stochastic flow with infinitely small space correlation radius. In

the second example we give description of the material lines for a stochastic flow with memory, characterizing by the finite Lagrangian correlation time and finite velocity space correlation radius.

B205

Lagrangian Transport and its Implications for Ocean Modeling

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(Abstract received 09/30/2002 for session B)

Dynamical systems ideas have given us a new view on Lagrangian transport in the ocean. With this perspective, the key structures are the invariant manifolds that delineate coherent features such as eddies and jets. This approach gives rise to efficient techniques for tracking and analysis of motion and the interaction of coherent features. This technique applied to optimal float placement design, Lagranian evaluation of ocean models, and analysis of the drifter/float data assimilation schemes.

B206

Material transport in the presence of wave-structures

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A Lagrangian stochastic model for material transport in the presence of wave-structures is presented. Simulated particle trajectories tend to be cycloidal. Velocity fluctuations aligned with the axis of the wave-structures are shown to be characterized by a non-oscillatory Lagrangian velocity autocorrelation function having a 'knee'(secondary maxima). Orthogonal velocities are characterized by an oscillatory Lagrangian velocity autocorrelation function having pronounced negative lobes. The coexistence of such distinct Lagrangian velocity autocorrelation functions together with the occurrence of cycloidal trajectories is the hallmark of Lagrangian data obtained from floats in the Equatorial Pacific Ocean. The chirality of trajectories, which can be determined from Lagrangian data, is shown to be key parameter.

B301

Surface Transport and Mixing in Monterey Bay: A First Look from Synoptic HF Radar Measurements

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Nearly continuous hourly HF radar observed surface currents in Monterey Bay, California are available for the period June 1999 through January 2000. We objectively map these measurements using a technique called normal mode analysis to fill spatial and temporal gaps, and to filter them in both space and time. The observations are projected onto two subsets of basis functions: vorticity modes and divergence modes. The mapped surface velocity field is used to evolve clusters of simulated drifters in the bay. Examples of drifter cluster evolution are presented to demonstrate the complexity of transport and mixing patterns suggested by the observations and to provide rough estimates of residence time scales inside the bay. The complex character of these simulated trajectories has motivated us to study hourly residence time maps in the bay created from large populations of simulated trajectories. These simulations are quite computationally intensive.

B302

Surface Transport and Mixing in Monterey Bay: A Turnstile Based Analysis without Hyperbolicity or Invariant Manifolds

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This talk analyzes surface transport in Monterey Bay using the velocity field described by Kirwan and Lipphardt. Particle trajectories are described by a finite time, nonstationary process. We extend the turnstile based transport analysis to this case without requiring the existence hyperbolicity or invariant manifolds. Statistical quantities related to particle passage through the bay are also computed using this approach. Results for both 1994 and 1999 are presented.

Collaborators in this effort are Kayo Ide, Denny Kirwan, Bruce Lipphardt, Chet Grosch, and Jeff Paduan.

B303

Surface Transport and Mixing in Monterey Bay: Escape Time/Location Analysis

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This talk analyzes surface transport in Monterey Bay using the velocity field described by Kirwan and Lipphardt. Particle trajectories are described by a finite time, nonstationary process and we describe a technique for studying whether a particle escapes to the open ocean, or has an encounter with the coast, as a function of space and time. Results for both 1994 and 1999 are presented.

Collaborators in this effort are Kayo Ide, Denny Kirwan, Bruce Lipphardt, Chet Grosch, and Jeff Paduan.

B304

Lagrangian Analysis and Prediction in Monterey Bay Using Finite-time Lyapunov Exponents of HF Radar Velocity Data: Application to Optimal Release of Contaminants

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High-frequency (HF) radar technology produces detailed surface velocity maps near the surface of estuaries and bays, such as Monterey Bay along the California coastline. The use of HF velocity data in environmental prediction, however, has remained unexplored. We uncover a striking Lagrangian structure in coastal radar observations of Monterey Bay. This complex structure governs the spread of organic contaminants from agricultural run-off, plasticizer manufacturing, and combustion of natural fossil fuels, all of which are typical sources of pollution in Monterey Bay. The release of pollution in coastal areas can lead to dramatic consequences for local ecosystems if the pollution recirculates close to the coast rather than being transported out to the open ocean and safely absorbed. We show that a release scheme which exploits the Lagrangian structure reduces the effect of industrial pollution in the coastal environment of the bay. This reduction is accomplished by using direct finite-time Lyapunov exponents of the HF radar data to predict optimal release windows in which contaminants are advected efficiently from the bay. We further demonstrate that sensitivity to initial conditions in coastal flows can create different patterns of behavior for released contaminants. Depending on their release position and release time, identical parcels of contaminants can have completely different trajectories and thus effects on the environment.

B305

Open-Boundary Modal Analysis: A Complete Functional Basis to Interpolate, Extrapolate and Filter Experimental Eulerian Data

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(Abstract received 11/01/2002 for session B)

Developments in dynamical systems theory have brought a wide range of methods that can be used to analyze and predict Lagrangian behavior in geophysical flows. However, it requires the ocean to be described as a dynamical system, that is, a fairly smooth differential equation. Increasingly accurate remote sensing techniques are available today and it is both appealing and unavoidable to be able to use the measured velocities directly to describe a dynamical system. Modal analysis has been used in the past 30 years to extrapolate and filter noisy and incomplete data sets. Up to recently, the modes used did not correctly allow flow across an open boundary of the domain. Open boundaries are an important concept when the domain is not completely closed by a shoreline, which is typical of coastal HF radar data. Previous modal analysis methods project the data only onto closed-boundary modes, andvthen used an ad hoc procedure to add a zero-order mode to allow flow across the boundary. This approach has many shortcomings, the primary one being that the projection is non-optimal. Numerically speaking, the approach we highlight also has many advantages, such as solving for the eigenfunctions on an unstructured (triangular) grid, which does not require the boundary to be either a staircase or a spline, as is typical with other modal analysis methods. We present the theory and a practical use of Open-boundary Modal Analysis (OMA), a complete set of eigenfunctions that can be used to interpolate, extrapolate and filter flows on an arbitrary domain with or without flow through a segment of the boundary. Finally, we demonstrate that other typical modal analysis methods reduce to OMA in the limit of a completely closed domain.

B306

A Lagrangian stochastic model for dispersion in unsteady inhomogeneous sub-filter scale turbulence

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(Abstract received 11/01/2002 for session B)

In many applications from the fluid dynamics laboratory to oceanographic flows, computer modelling or observational data typically results in a discretized velocity field. The knowledge we have of the flow under study is limited by the spacing between grid points in space and time. In a laminar flow, this limited knowledge may be adequate to sufficiently describe how particles are advected through this flow. But, in a turbulent flow, we need a way to determine the effect of the sub-grid or more generally, sub-filter scale, below which structure is not resolve, on particle advection. Many attempts in oceanographic and other fields have been made to model the unresolved Lagrangian dynamics as an Ornstein-Uhlenbeck process by assuming homogeneity and stationarity of the velocity statistics at the sub-grid scale. We overcome this limitation through the employment of a more sophisticated Lagrangian stochastic (LS) model capable of capturing inhomogeneous and unsteady effects. This LS model is used to investigate the relationship between small-scale turbulent dispersion and Lagrangian coherent structures in a quasigeostrophic double-gyre model and in HF radar velocity data of Monterey Bay. The existence of coherent structures mandates the use of a LS model which adapts to temporal and spatial variations in the prescribed flow.

B307

A new approach to transport in the large-scale ocean circulations

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(Abstract received 11/15/2002 for session B)

We present a new transport method to study the effects of the unsteady eddies on the transport of the large-scale circulations in the oceans. The new method is a hybrid of the Lagrangian and Eulerian methods, and called TIME theory (transport induced by mean-eddy interaction). A simple analysis suggests that the ratio of the characteristic time scales of the dynamic variability and length scales of the instantaneous flux controls the efficiency of transport.

Section C Abstract

C101

http://OceanCurrents.rsmas.miami.edu

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(Abstract received 09/14/2002 for session A)

A web-based ocean current reference site is being constructed at the Rosenstiel School of Marine and Atmospheric Science, U. of Miami. Each major ocean current is planned to have a listing of important links, text, and data plots. The text provides a detailed summary of observed velocities, transport, temperature, and variability for each current. Data plots include average and seasonal surface current fields derived from ship-drift, sea surfacetemperature maps, near-surface drifter trajectories, and output from numerical simulations by the NOPP-funded HYCOM Consortium for Data-Assimilative Ocean Modeling. We are currently working on Atlantic Ocean Surface Currents. An overview of the site and examples of near-surface trajectories in ocean currents and gyres will be presented. (http://OceanCurrents.rsmas.miami.edu)

C104

Efficient Navigation and Adaptive Sampling Strategies for Fleets of Autonomous Underwater Gliders

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(Abstract received 10/31/2002 for session A)

An underwater glider is a fixed-wing, buoyancy-driven autonomous underwater vehicle with the ability to redistribute its internal mass to effect net changes in attitude. In addition, fixed wings provide lift to induce forward motion for non-zero angles of attack. By design, underwater gliders are reliable and efficient--making them well-suited for long duration ocean sampling, especially in the context of multi-vehicle, mobile, adaptive sampling networks.

In this talk we describe how fleets of coordinated underwater gliders can act as ocean sensors for adaptive sampling. Ocean currents undoubtedly affect glider motion; hence it is important to utilize the natural dynamics of the flow when developing efficient navigation schemes. We propose a strategy that uses Direct Lyapunov Exponent (DLE) contours to lead the gliders toward areas of sampling interest, e.g. fronts. Repelling material lines obtained from DLE maps computed forward in time are used as navigation channels. The gliders track these repelling material lines to reach fronts that coincide with attracting material lines, which are obtained from DLE maps computed backward in time. We present control methods that enable groups of gliders to climb gradients of DLE fields as one mean of tracking the navigation channels.

The control laws that we propose to coordinate the gliders derive from artificial potentials. The idea is to impose simple feedback rules at the individual glider level that enable more complex group-level behaviors such as formation maintenance, group translation, rotation and expansion in response to measured data. These types of behaviors can then be put together to perform tasks such as gradient climbing or sampling in and around a front or feature of interest. We illustrate the latter idea by considering an example whereby we induce a formation to roll along a sensed front (e.g. temperature). The net group motion is along the front but each vehicle visits the front boundaries repeatedly, thus sampling both the interior and across the boundaries.

C105

TELEPHOS: A new surface drifter for coastal and lake studies

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(Abstract received 11/08/2002 for session C)

This work constitutes the presentation of a new surface drifter, designed for use in semi-enclosed seas, coastal areas and lakes. The booming growth of cellular phone market worldwide has brought large coastal areas under the coverage of GSM telephony. Not only coastal regions and lakes, but even semi-enclosed seas, like the Baltic, enjoy almost full coverage by cellular telephony. This enables the introduction of such technology in replacing satellite communication, resulting to significantly lower costs. Furthermore, the decentralization allowed by the use of such technology, enables the monitoring of drifters

in real-time and data-analysis in near-real time, offering drifter methodologies to operational oceanography applications. Furthermore, the real-time monitoring and interactive, reprogrammable software, allow the easy tracking and recovery of drifters, thus lowering their cost by making them less expendable instruments. Our new design allows the alternate use of a drifter either as surface, Davis-type drifter, or as a surface float with a subsurface kite down to depths of 50 m. Finally, the software accompanying the drifters allows not only mission programming and drifter monitoring, but also considerable data analysis (Eulerian statistics, Lagrangian estimates of diffusivity, spectral analysis, etc). As the construction of the prototype drifters is under way, the software presentation of the data analysis part is based on data collected by WOCE drifters deployed by R.S.M.A.S. in the Aegean Sea in 2001-2002, in collaboration with the Hellenic National Centre for Marine Research.

C201

Synoptic Comparisons of Numerical Simulations with Drifter Observations of JES Circulation

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(Abstract received 11/01/2002 for session A)

The Princeton Ocean Model (POM) has been implemented for the Japan (East) Sea (JES) with mesoscale-admitting resolution and driven by seasonal throughflow and synoptic atmospheric forcing for 1999 through 2001; this implementation is referred to as JES-POM. Observed temperature/salinity profiles and horizontal velocities at 800 m from PALACE float trajectories are used to assess the performance of JES-POM simulations. The PALACE float temperature and salinity profiles validated the JES-POM simulated seasonal cycle and identified some significant differences. The mean observed flow at 800 m defines a large cyclonic recirculation gyre over the Japan Basin that validates the simulated flow pattern; however, the simulated speeds were about twice those observed. The variance of the observed and simulated flow at 800 m had similar patterns; however, the simulated variance was about one-half the observed variance. Also, mean circulation and EKE distributions derived from surface WOCE drifters are compared with simulations.

Acknowledgement: Dr. Steve Riser, University of Washington, provided PALACE float data and Dr. Dong-Kyu Lee, Pusan National University, provided maps of surface mean circulation and EKE.

C202

Quantitative estimate of inter basin exchanges in the Mediterranean Sea from Lagrangian diagnostics applied to a OGCM

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Lagrangian diagnostics is used to quantify mass transport in the main pathways of the upper and lower cells of the Mediterranean thermohaline circulation (THC) as they results from OGCM simulations. About 500 000 particles are integrated off-line using daily averaged velocity fields from a Mediterranean OGCM and the characteristic times of the THC are studied by means of the pdf distribution of particles transit times betwen the different regions of the basin.

The Mediterranean Sea is an evaporative basin in which the deficit of water is supplied by the inflow from the Gibralyar Strait of Atlantic Water (AW). The net result of the air sea interactions in the entire basin is an outflow at Gibraltar of a alty water that is mainly constituted by the Levantin Intermediate Water (LIW), formed in the eastern part of the basin. Despite this simplified pattern, the circulation in the Mediterranean is rather complex. Most of the Mediterranean Sub basins are characterized by water mass formation processes and thepresence of sills and straits strongly influence both the spreading and the mixing of intermediate and deep waters.

In this context the Lagrangian diagnostics reveal to be very useful to quantify both mass transport between different regions and theassociated spectrum of transit times.

C203

A Catch-and-Release Drifter that Resolves Characteristic Scales of Coastal Dynamics

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(Abstract received 10/02/2002 for session C)

An improved drifter for use in the coastal zone is presented. The near-shore drifter records position with GPS and transmits position data in near real-timeusing the Mobitex narrow band, data-only, cellular communications system. Driftr position is accurate to within 10 meters in the southern California region. Position updates can be recorded and transmitted every minute. The spatial and temporal resolution enables characteristic near-shore circulation patterns to be properly resolved. Spatial accuracy and near real-time data transmission make the drifters recoverable, so they can be used in catch-and-release manner. Rechargeable Ni-Cad batteries support communications for more than a week when sampling every 10 minutes. The drifters employ a Tri-Star type drogue at 1 m with slip believed to be 0.1-0.2%of the wind speed. Field tests suggest cellular coverage is adequate for reliable communications throughout almost the entire Santa Barbara channel (20 km offshore). Drifters are expected to properly update and communicate when located on the continental shelf off the shore of other coastal cities. Three preliminary deployments of up to 18 drifters occurred between 29 April and 2 May 2002 off the Santa Barbara coast. Conditions during the period ranged from calm to rough, with sustained winds over 12 m/s and 3 to 6 foot wind waves (NOAA/NWS buoy 46053). Drifters were released on the inner-shelf in water depths between 15 and 80 m. Drifters typically transmitted their position every 10 minutes for a single day, but were left to sample continuously for up to 5 days. Occasional data losses and erroneous GPS position updates occurred due to a problem with configuration of the drifter GPS modules (believed to be remedied). All drifters were recovered and are available for future use. Repeated deployments of the coastal drifters will greatly enhance the understanding of near-shore circulation.

C204

Mean and variability of the flow from quasi-Lagrangian floats

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(Abstract received 10/15/2002 for session C)

Quasi-Lagrangian trajectories from profiling floats deployed in the tropical Atlantic are used to derive the mean flow and the variability at intermediate depth (800-1100m) for January to June and for July to December. The mean fields as well as individual trajectories reveal reversals of the flow on the equator. Indications for such reversals were also found in Lagrangian trajectories obtained during earlier experiments and they are confirmed in comparisons of Eulerian observations collected at different times of the year. Signs for reversals are also found at off-equatorial latitudes (e.g. 6°S, 6°N). Differences between the equatorial band (roughly 3°S to 3°N) and the region outside of this band are present in the vertical and zonal extent of unidirectional zonal flow. There are also signs for differences in the temporal variability of the flow. To date the best coverage with data from profiling floats in the tropical Atlantic is found around 6°S. Therefore the latitude band 5°-7°S is chosen for an analysis of the temporal variability of the flow outside of the equatorial band. It is found that the zonal velocity reverses on an annual time scale, and that the time of reversal depends on the longitude. In addition shorter-periodic variability is observed. In some cases westward propagating signals can be identified in a longitude-time diagram. Their propagation can be associated with an apparent westward phase velocity on the order of 6cm/s. Similar characteristics are found in a numerical model with time-varying climatological winds. It is possible to derive a longitude-time diagram of the velocity that is strikingly similar to that from the model with a superposition of only two planetary waves.

C301

Surface Wave and Shear Measurements with Surface Drifter

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CODE surface drifters were equipped with Nortek Aquadopp acoustic velocimeters and with GPS receivers, without changing significantly their hydro-dynamical characteristics (e.g., size, buoyancy and drag area). The velocimeters measured the relative water flow at two levels (~ 30 and 130 cm below the sea surface) near the body of the drifter with an accuracy of about 1 cm/s and with sampling frequency of 1 Hz. The GPS receivers provided high accuracy (~ 1 m) position data at 1 Hz. All the data were recorded on a data logger and memory board inside the drifters. The drifters were operated in Monterey Bay (Eastern North Pacific) in late fall 2000 and in the Northern Adriatic Sea in spring and fall of both 2001 and 2002. The majority of the deployments were conducted in the vicinity of

waverider buoys, an oceanographic tower and research vessels from which wave and wind data were collected. Data of the Nortek Aquadopp (relative flow, tilt, pressure) and of the GPS receivers were processed and their high-frequency components were analyzed. Spectral analysis revealed robust surface wave signals similar to those measured by nearby waverider buoys or by bottom pressure gauges (at oceanographic tower). The relative flow data from the top and bottom velocimeters were projected onto the horizontal plane and averaged over 10 min intervals. Vertical shear of the horizontal currents were calculated and projected in the down and across-wind directions. Shears of up to 11 cm/s were found. Regressions of shear versus wind speed indicated that the shear is downwind and to the right of the wind (compatible with Ekman spiral), and that it increases with wind speed.

C302

Direct Measurements of Water-following Characteristics of CODE Surface Drifters

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(Abstract received 10/31/2002 for session C)

The water-following capabilities of the CODE surface drifter were assessed by making direct measurements of the effects of wind and waves on its movements. The CODE drifter was equipped with acoustic velocimeters and with GPS receivers, without changing significantly its hydro-dynamical characteristics (e.g., size, buoyancy and drag area). The velocimeters measured the relative water flow at 1-2 locations near the body of the drifter with an accuracy of about 1 cm/s and with sampling frequency of 1 Hz. The GPS receivers provided high accuracy (~1 m) position data at 1 Hz. All the data were recorded on a datalogger and memory board inside the drifter. The CODE drifter prototype was deployed in the vicinity of a waverider buoy in Monterey Bay (Eastern North Pacific) in December 2000 and in the northeastern Adriatic in March 2001. It was also deployed in the vicinity of the "Acqua Alta" oceanographic tower off Venice (northwestern Adriatic) in November 2001 and April 2002. The ship used for the deployment/recovery operations was fitted with a meteorological station to collect wind data close to the drifter. The drifter was operated in various wind/wave conditions, with wind speeds ranging in 0-15 m/s and significant wave height between 0 and 2.5 m. Regression were performed between the 10-min averaged relative flow data, the wind and wave observations. It was found that the slip of the CODE drifter has no significant trend in the downwind direction whereas it increases with wind speed in the cross-wind direction (to the right). In summary, the CODE drifter was demonstrated to follow relatively well the surface water with an accuracy of about 1 cm/s in 10 m/s winds.

C303

Vortex statistics from Eulerian and Lagrangian time-series.

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(Abstract received 09/23/2002 for session D)

Coherent vortices are an important component of the dynamics of geophysical turbulence, but direct estimates of the properties of the vortex population from measured data is usually difficult. Motivated by this problem, we propose a new method for determining the statistical properties of coherent vortices in two-dimensional turbulence based on a small number of Lagrangian and Eulerian time series. The method provides reliable estimates of the mean vortex size and vortex number density.

C304

Reconstruction of near-surface drifter trajectories in the Pacific Ocean with a hybrid model

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(Abstract received 10/15/2002 for session D)

A hybrid Lagrangian-Eulerian model for calculating the trajectories of near-surface drifters in the ocean is developed in this study. The model employs climatological, near surface, currents computed from a spline-fit of all available near surface drifter velocities observed in the Pacific Ocean between 1988 and 1996. It also incorporates contemporaneous wind fields calculated by either the US Navy (Navy Operational Global Atmospheric Prediction System - NOGAPS) or the European Centre for Medium Range Weather Forecasts (ECMWF). The model was applied to 30 drifters launched in the Pacific Ocean in 3 clusters during 1990, 1993 and 1994 (no ECMF winds were available for this year). For 10-day-long trajectories the forecasts computed by the hybrid

model are up to 164% closer to the observed trajectories compared to the trajectories obtained by advecting the drifters with the climatological currents only. The best fitting trajectories are computed with ECMWF fields that have a temporal resolution of 6 hours. The average improvement over all 30 drifters of the hybrid model trajectories relative to advection by the climatological currents is 21% but in the open ocean clusters (1990 and 1993) the improvement is 34% with NOGAPS winds and 42% with ECMWF winds. This difference between the open ocean and coastal clusters is due to the fact that the model does not presently include the effect of horizontal boundaries (coastlines). For unknown initial velocities the trajectories generated by the hybrid model are significantly more accurate than advection by the mean currents on time scales of 5-15 days. Given the real-time availability of NOGAPS wind stress and the existence of on-line atlases of near surface ocean currents, the model provides a practical tool for forecasting the trajectories of surface drifters. On time scales of 3-days significant improvement is achieved only if the drifters' initial velocities are known. The model's success in providing more accurate trajectories also indicates that drifters' motion can deviate significantly from the climatological current and that the instantaneous winds are more relevant to their trajectories than the mean currents. A possible interpretation of our results is that the winds' role in drifter dynamics is more significant than its role in the water velocity since drifters do not have to obey the continuity equation.

Section D Abstracts

D101

Simple prediction algorithms for the Lagrangian motion

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(Abstract received 09/27/2002 for session D)

A new algorithm is suggested for prediction of the position of an unobserved Lagrangian particle (predictor) in a stochastic flow given observations of other particles (predictors). The algorithm is similar to the classical center of mass (CM) procedure, but takes essentially into account the initial position of the predictand. It appears to be efficient for an initial tight cluster and small prediction time. A theoretical error analysis is given for the Brownian flow and a stochastic flow with memory. The asymptotic formulae are compared with simulation results to establish their applicability limits. Monte-Carlo simulations are carried out to compare the new algorithm with two others: CM and a Kalman filter type method. The algorithm is also tested on real data in the Tropical Pacific. We also present preliminary results concerning with the optimal initial predictor placement for CM algorithm.

D102

Lagrangian Predictability, Hyperbolicity, and Optimal Observing Strategies for the Ocean

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(Abstract received 09/25/2002 for session D)

Predictability studies in meteorology tend to focus on error growth on Eulerian time-scales. In contrast Lagrangian predictability plays a bigger role in oceanography because of the availability of trajectory data from drifters and floats. Tracking and mapping the hyperbolic trajectories that govern the time evolving boundaries of coherent structures is crucial to understanding Lagrangian predictability. We summarize results from basin-scale numerical drifter experiments that employ Lagrangian templates based on a-priori knowledge of hyperbolic trajectories in the model field. Using a reduced gravity primitive equation model it was found that drifter deployments aligned along outflowing material curves provided the maximum Lagrangian data coverage and hence highest accuracy of Eulerian fields reconstructed from the Lagrangian data. This result is in contrast to other strategies based on random deployments or deployments in high velocity regions. Preliminary results from a study with a data assimilating general circulation model of the Gulf of Mexico are also discussed. The talk concludes with an outline of a Lagrangian predictability experiment.

D103

Assimilation of drifter observations for the reconstruction of the Eulerian circulation field

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(Abstract received 09/26/2002 for session D)

In light of the increasing number of drifting buoys in the ocean, and recent advances in the realism of ocean general circulation models toward oceanic forecasting, the problem of assimilation of Lagrangian observations data in Eulerian models is investigated. A new and general rigorous approach is developed based on optimal interpolation methods, which takes into account directly the Lagrangian nature of the observations. An idealized version of this general formulation is tested in the framework of identical twin-experiments using a reduced-gravity, quasi-geostrophic model.

An extensive study is conducted to quantify the effectiveness of Lagrangian data assimilation as a function of the number of drifters, the frequency of assimilation and uncertainties associated with the forcing functions driving the ocean model. The performance of the Lagrangian assimilation technique is also compared to that of conventional methods of assimilating drifters as moving current meters, and assimilation of Eulerian data, such as fixed-point velocities. Overall the results are very favorable for the assimilation of Lagrangian observations to improve the Eulerian velocity field in ocean models. The results of our assimilation twin experiments imply an optimal sampling frequency for oceanic Lagrangian instruments in the range of

20-50% of the Lagrangian integral time scale of the flow field.

D104

Assimilation of drifter observations in primitive equation models of midlatitude ocean circulation

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(Abstract received 09/26/2002 for session D)

Motivated by increases in the realism of OGCMs and the number of drifting buoys in the ocean observing system, a new Lagrangian assimilation technique developed by Molcard et al. (2002) is implemented in an idealized configuration of the layered primitive equation model MICOM. Using an extensive set of twin experiments, the effectiveness of the Lagrangian observation operator and of a dynamical balancing technique for corrected model variables, which is based on geostrophy and mass conservation, are explored in comparison to a conventional Pseudo-Lagrangian observation operator and a ROIF implementation of the Kalman filter method (Chin et al., 1999). The Pseudo-Lagrangian operator relates the Lagrangian velocity from drifter data to the Eulerian model velocity, whereas the Lagrangian operator relates the Lagrangian velocity from drifter data to the Lagrangian velocity from model-simulated drifters. The Kalman filter is implemented in the Pseudo-Lagrangian mode, and provides a general reference for assimilation performance.

The results clearly illustrate that the Lagrangian observation operator is superior to the Pseudo-Lagrangian in the parameter range that is relevant for typical oceanic drifter observations. The results not only support the validity of the simple dynamical balancing technique, but they also indicate that the correction of model velocity field must be accompanied by an appropriate correction of layer thickness (or pressure, depending on model formulation) for such assimilation to be effective.

Chin, T.M., A.J. Mariano, and E.P. Chassignet, 1999: Spatial regression with Markov Random Fields for Kalman filter approximation in least-squares solution of oceanic data assimilation problems. JGR Oceans, 104, 1233-1257.

Molcard, A., L.I. Piterbarg, A. Griffa, T.M. Özgökmen, and A.J. Mariano, 2003: Assimilation of drifter observations for the reconstruction of the Eulerian circulation field. JGR Oceans, in press.

D105

A direct data assimilation method for Lagrangian observations

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(Abstract received 11/15/2002 for session D)

We present a new method for assimilating the Lagrangian observations directly into the model. The method is based on the extended Kalman filtering of the sequential approach. Most data assimilation systems in meteorology and oceanography use Eulerian models that compute the prognostic variables on a stationary grid. So far, in order to use Lagrangian observations given as trajectory data, they convert the data into Eulerian velocity by statistical interpolation. Doing so may lose precious time-integrated dynamical information hidden in the trajectories.

Our new method augments the trajectories to the prognostic variables of the model. This introduces the error correlation between the original model variables and the trajectories. Therefore, it provides a natural platform for direct assimilation of the Lagrangian observation in the framework of the extended Kalman filtering.

D106

A method for assimilation of Lagrangian tracer measurements

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(Abstract received 09/30/2002 for session D)

A new method that affords direct assimilation of Lagrangian tracer measurements into the ocean model is presented. The model is augmented with tracer advection equations and the correlations between the flow and the tracers are tracked via the extended Kalman filter. The augmented model state vector includes tracer coordinates and is updated through the correlations to the observed tracers. The technique works efficiently when the observations are accurate and frequent enough. Low quality data and large intervals between observations can lead to

the divergence of the scheme. Nonlinear effects, responsible for the failure of the extended Kalman filter, are triggered by the exponential separation rate of tracer trajectories in the neighborhood of the saddle points of the velocity field. Implications of these results for optimal launching strategy design and an extension of our method to realistic ocean models are discussed.

D107

Assimilation of simulated float data into the viscid Lagrangian shallow water model

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(Abstract received 10/11/2002 for session D)

Our goal is to accurately assimilate Lagrangian data into numerical ocean circulation models, including open ocean models. The forward model is written in Lagrangian coordinates, thus Lagrangian data does not need to be interpolated for assimilation. We shall in due course consider open ocean problems for the primitive equations, since these are well posed if the domain is Lagrangian. The boundaries of such domains are simple in Lagrangian coordinates. The expense of this approach is a highly nonlinear viscous stress divergence. At the 2001 LAPCOD meeting we showed that the forward viscous Lagrangian shallow water model in double periodic domains can reproduce the eddy field for a time period over a hundred days, with grid Reynolds numbers as large as 5 but not 10.

In previous work (Mead and Bennett 2000) we used variational data assimilation to assimilate simulated float data into the inviscid Lagrangian water model for time periods of a few hours. Here we will show assimilation results from twin experiments with the viscous Lagrangian model for time periods on the order of two weeks.

D108

Assimilation of lagrangian data into an eddy resolving ocean model: the special case of ARGO float displacement data

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(Abstract received 11/06/2002 for session A)

Within the SHOM/BRESM assimilation group in Toulouse, France, we are investigating means of assimilating ARGO float displacement data into a regional open-boundary implementation of MICOM. The model area covers a small part of the North Atlantic Ocean off the portugese coast, where intensive surveys and float releases were performed in years 2000 and 2001 within the french POMME experiment.

Our special topic of interest is the behaviour of assimilation methods with respect to mesoscale structures such as eddies and fronts. The ARGO float cycle of typically 10 days introduces weak or strong aliasing of the structures.

The methods beeing developed and tested include various implementation of objective analysis as well as variational methods. Our approach is pragmatic : the methods are implemented and their performances for analysis and forecast are compared. We will expose our model and assimilation setup and show some preliminary results.

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