Predictability of Particle Trajectories in the Ocean

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LONG-TERM GOALS

The long term goal of this project is to determine optimal sampling strategies for drifting buoys, in order to enhance prediction of particle motion in the ocean, with potential applications to ecological, search and rescue, floating mine problems, and design of observing systems.

OBJECTIVES

To develop methods for the objectives of ODDAS DRI, which is to preserve the sampling volume of an acoustic sensor array, and replenish when gaps in the observational volume occur due to the dispersion of the sensors with the underlying Eulerian flow field.

APPROACH

The work is based primarily on stochastic and dynamical models of particle motion and data assimilation strategies. It also involves the use of coastal circulation models and processing of oceanic data such as drifter positions, ocean surface currents, and wind field.

WORK COMPLETED

1) Acceptance of a paper on parameterization of submeso-scale eddy fields as observed by high-frequency coastal radars using a stochastic Eulerian velocity model (Caglar et al., 2006).

2) Acceptance of the Lagrangian Analysis and Predictability of Coastal and Oceanic Dynamics (LAPCOD) book, which was edited by all PIs of this project as well as by D. Kirwan (U. Delaware) and T. Rossby (URI), by the Cambridge University Press. The book is in production to be published in March 2007.

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3) Participation in both the winter and summer cruises of the DART (Dynamics of the Adriatic in Real Time) observational program, in order to provide guidelines for targeted release of drifters.

4) Development and implementation of a computational scheme in order to incorporate the effect of unresolved turbulent motion on Lagrangian particle transport (Haza et al., 2006). Related work is being conducted in order to quantify the exact influence of turbulent flows on the O(1 km) on particle motion using NCOM.

5) Continuation of work on stochastic boundary conditions (Chin et al., 2006).

RESULTS:

1) *DART and targeted drifter launch strategies:*

PIs (Griffa, Özgökmen) and postdoc (Angelique Haza) have participated in the drifter release component of Dynamics of the Adriatic in Real Time (DART) experiment conducted jointly by NATO-NURC (led by Michel Rixen) and NRL (led by Jeff Book). DART was an extensive observational and modeling experiment. Our participation concerned mainly the determination of drifter release locations for best sampling of the dynamical features. The primary methods to determine the launch locations relied on 2-day hindcasts and 2-day forecasts from NCOM, the outputs of which are provided to us by Paul Martin from NRL. This model has very high resolution (1 km, 1 hour) and is driven by 4-km resolution COAMPS atmospheric forcing, tides and rivers. The main goal of our drifter launches during the winter (March 2006) cruise has been to pinpoint the location of a prominent hyperbolic point, which arises due to vortex stretching over the Palagruza Sill in the middle of the Adriatic. Such hyperbolic points can facilitate high levels of particle dispersion, and thus are useful to increase the sampling coverage. While the concept of hyperbolic points as prominent features controlling Lagrangian dispersion is well developed in theory and numerical models, their existence and influence in reality requires more support from observations. During the second cruise (August 2006), the main effort was spent on capturing the recirculating eddies forming downstream of the Gargano Cape. Such eddies appear to form mostly in the summer season and have a significant impact on coastal regions by entraining water masses off the coastal shelf. Two methods have been used. First, historical data sets have been analyzed based on drifters released by P. Poulain in the Adriatic Sea over the last decade. Second, the intersection points of finite-scale Lyapunov exponents (FSLEs) from 2-day backward and 2-day forward particle integrations have been traced. We emphasize that FSLEs are not only useful to detect hyperbolic points and shear zones, which are useful to enhance coverage and independent sampling, but also zero-FSLE regions are suitable for transport of particle clusters without deformation and dispersion, which is one of the optimization criteria of ODDAS. *To our knowledge, this is the first time that targeted drifter launch strategies have been employed real-time during an observational program.*

We have conducted a preliminary analysis of data collected in the winter cruise in comparison to predictions based on NCOM fields. During this experiment (March 11-23, 2006), a total of 17 drifters were launched, of which 12 have survived for a period longer than 2 days. Trajectories of all these drifters are shown in Fig. 1. They provide a good

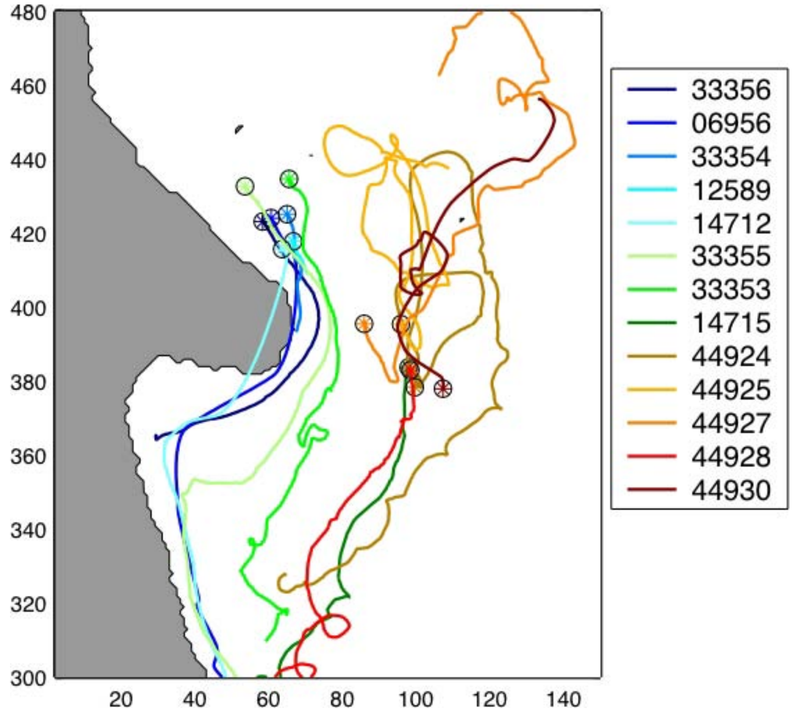

Figure 1: Trajectories of DART drifters during March 11-30.

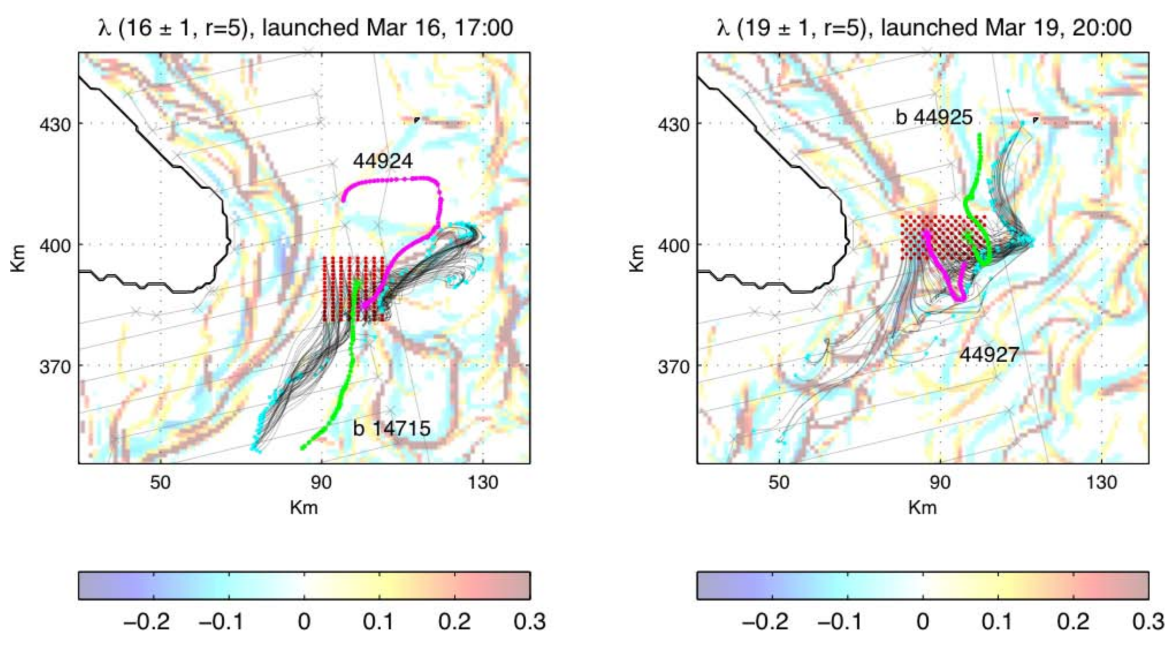

Figure 2: Comparison of the real DART (green and pink) and synthetic NCOM (black) trajectories from the March 2006 experiment. Two drifters were launched based on finite-scale Lyapunov exponents (plotted in the background) from the NCOM daily output, and constraints due to the predetermined cruise path (regular gray line in the background). Note that clusters of synthetic trajectories provide a reasonable prediction of the real surface drifter motion.

coverage of the region, including the boundary current and the interior, which indicates that one of the overall goals of the experiment was achieved. In order to examine the whole data set, we re-initialized daily the synthetic trajectories around the observed drifter positions and integrated forward for 7 days. Daily initialization is motivated by the fact that the Lagrangian time scale in this region is approximately 1-1.5 days, so that results on Lagrangian predictability are expected to be independent over 1 to 2 day intervals.

By far the most striking result from this analysis is that NCOM can satisfactorily describe surface Lagrangian transport (Fig. 2) in the Adriatic Sea, which is very promising for operational programs. The summer experiment involved rather dramatic changes between Bora (recirculating eddy suppressing) and Scirocco (recirculation eddy favoring) winds. Overall, DART experiment was an excellent opportunity not only for testing Lagrangian methods in real-time applications, but also for establishing new collaborations with scientists specializing in operational oceanography (M. Rixen, P. Martin, J. Book) and maintaining research with others (A. Molcard, P. Poulain). We envision to publish two joint papers from these experiments, a short descriptive one to be prepared in 2006, and a comprehensive paper on the Lagrangian component in 2007. In addition to Lagrangian research, one of the byproducts of our DART participation is that other in-situ and remote sensing observations will be useful for the Ph.D. dissertation of M. Marcello on the impact of capes on coastal circulation, and M. Rixen will serve in his committee.

2) *Lagrangian subgridscale model for transport improvement:*

An accurate estimation of Lagrangian transport in the ocean is important for a number of practical problems such as dispersion of pollutants, biological species, and sediments. Forecasting of the Lagrangian pathways necessarily relies on the accuracy of ocean and coastal models. However, these models include a number of errors due to forcing, missing physics and unresolved turbulence that propagate directly from the Eulerian velocity field to the Lagrangian transport.

In this study (Haza et al., 2006), a method is developed in order to reduce errors in Lagrangian transport by employing the statistical drifter behavior estimated from observational data sets. The method is shown to work well using both a so-called Markov velocity field model, representing an idealized turbulent flow field, and in the context of NCOM configured in the Adriatic Sea for realistic, high-resolution, complex ocean flows
(Fig. 3).

The simplicity and computational efficiency of this technique, combined with applicability to ocean models at a wide range of resolutions, appears promising in light of the challenge of capturing exactly the oceanic turbulent fields, which is critical for Lagrangian dispersion.

3) Impact of small-scale turbulent flows on particle motion:

Traditionally, the impact of small-scale turbulent flows, such as inertial oscillations, divergence/convergence zones near coastal flows generated by upwelling/downwelling, strong wind events and vertical mixing have been neglected. This is not only due to inadequate space/time sampling of the observations, but also because Lagrangian methods

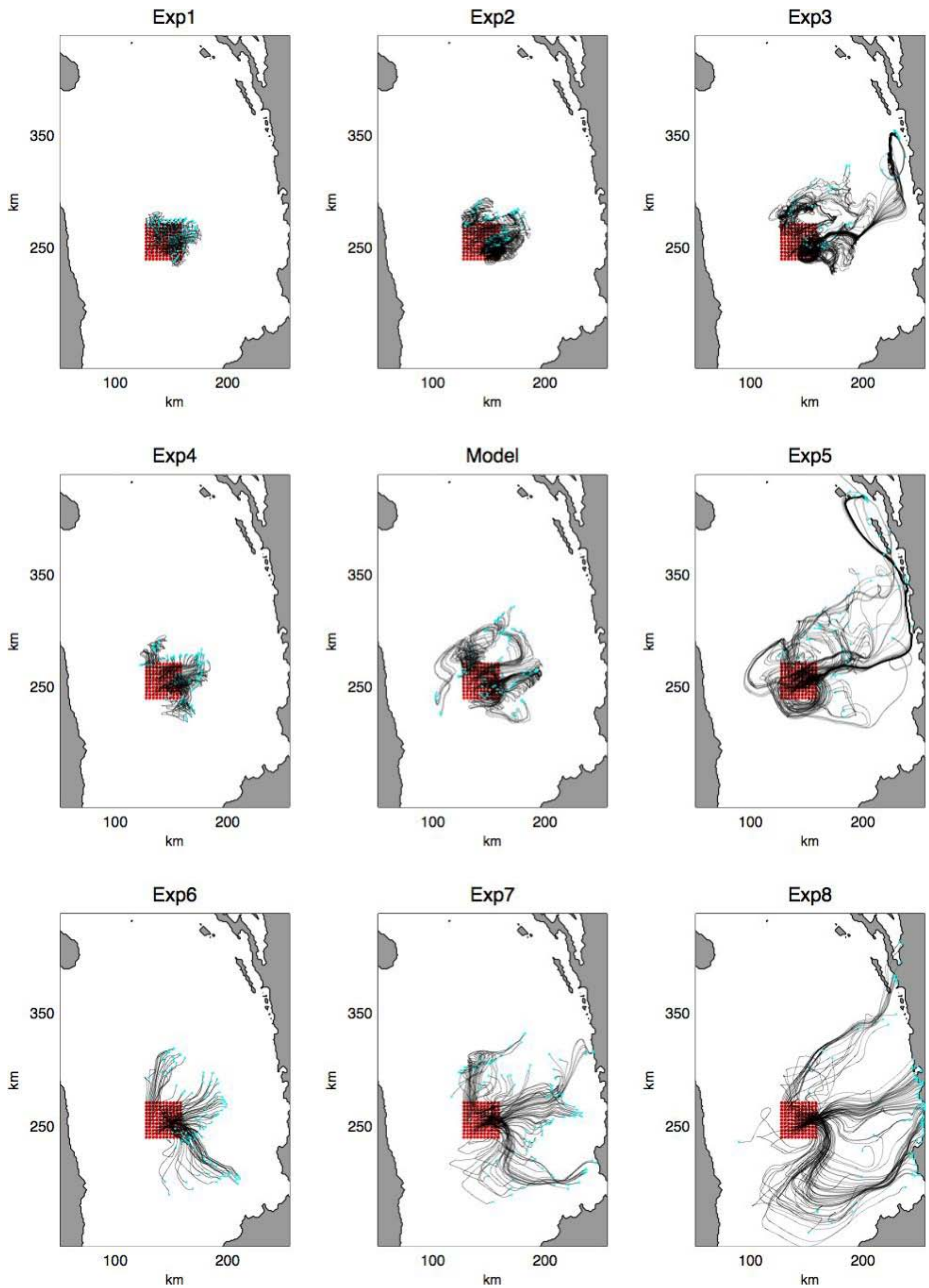

Figure 3: Fifteen-day long trajectories of 121 particles from Adriatic NCOM in various experiments where the parameters of the Lagrangian subgridscale model are varied to modify the model-generated trajectories (middle panel) to be much less (upper left panel) or much more (lower right panel) energetic (Haza et al., 2006).

based on dynamical system theory often work well only in flow regimes, in which the Lagrangian time scale is smaller than the Eulerian time scale. In light of very high-frequency sampling (e.g., GPS) data sets becoming available for oceanic community, high-resolution numerical models, highly variable nature of coastal surface flows (e.g., NCOM and DART experiment), the question arises how metrics quantifying dispersion of particles, such as FSLEs, are sensitive to time/space filtering of scales. If they are sensitive, what can be done to compensate for the dynamics filtered out during such space/time averaging? These problems are being pursued with A. Poje (CUNY) based on high-resolution outputs of NCOM in the Adriatic. Our initial finding confirms that time smoothing changes the behavior of particle dispersion (Fig. 4). The impact of space smoothing will be tackled next.

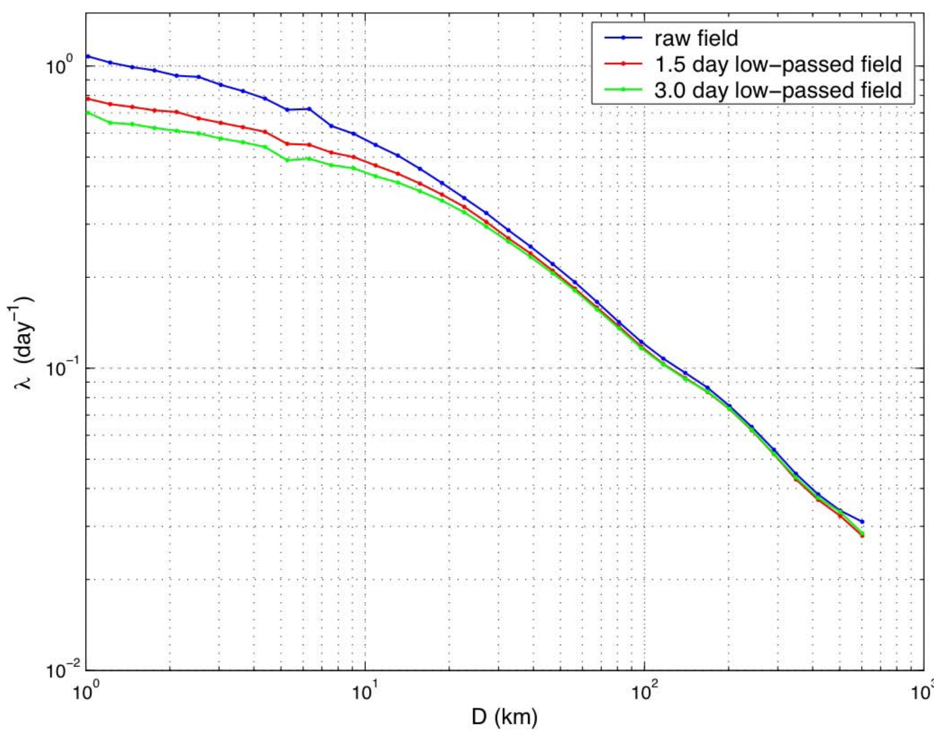

Figure 4: Dependence of FSLE on particle separation distance estimated from NCOM configured in the Adriatic. This plot shows that low-pass filtering with 1.5 and 3-day intervals (red and green curves, respectively) leads to significant errors in submesoscale relative dispersion behavior, but large-scale dispersion is minimally effected.

IMPACT/APPLICATIONS

The investigation of the predictability of particle motion is an important area of study, with a number of potential practical applications at very different scales, including searching for persons or valuable objects lost at sea, tracking floating mines, ecological problems such as the spreading of pollutants or fish larvae, design of observing systems and navigation algorithms.

RELATED PROJECTS

Lagrangian Turbulence and Transport in Semi-Enclosed Basins and Coastal Regions, PI: A. Griffa, N00014-05-1-0094.

Statistical and Stochastic Problems in Ocean Modeling and Prediction, PI: L. Piterbarg, N00014-99-1-0042.

Optimal Deployment of Drifting Acoustic Sensors: Sensitivity of Lagrangian Boundaries to Model Uncertainty, PI: A. Poje, N00014-04-1-0192.

PUBLICATIONS (2005-2006)

Refereed publications:

Molcard, A., A.J. Poje, and T.M. Özgökmen, 2005: Directed drifter launch strategies for Lagrangian data assimilation using hyperbolic trajectories. Ocean Modelling, 22/1, 70-83.

Griffa, A., A.D. Kirwan, A.J. Mariano, T.M. Özgökmen and T. Rossby, 2007: Lagrangian Analysis and Prediction of Coastal Ocean Dynamics. Cambridge University Press, in press.

Piterbarg, L.I., T.M. Özgökmen, A. Griffa, and A.J. Mariano, 2007: Predictability of Lagrangian motion in the upper ocean. LAPCOD book chapter, in press.

Molcard, A., T.M. Özgökmen, A. Griffa, L.I. Piterbarg, and T.M. Chin, 2007: Lagrangian data assimilation in ocean general circulation models. LAPCOD book chapter, in press.

Caglar, M., T.M. Özgökmen, and L.I. Piterbarg, 2006: Parameterization of submeso-scale eddy- rich flows using a stochastic velocity model. J. Atmos. Ocean Tech., in press.

Haza, A., L.I. Piterbarg, P. Martin, T.M. Özgökmen and A. Griffa: A Lagrangian subgrid-scale model and application for transport improvement in the Adriatic Sea using NCOM. Ocean Modelling, in revision.

Chin, T.M., T.M. Özgökmen, and A.J. Mariano: Empirical and stochastic formulations of western boundary conditions. Ocean Modelling, in revision.