Optimal Deployment of Drifting Acoustic Sensors: Sensitivity of Lagrangian Coherent Structure Boundaries to Model Uncertainty

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LONG-TERM GOALS

Our long-term goal is to provide a template for the launch locations of drifting Lagrangian measurement platforms that will maximize the amount of environmental information provided by a necessarily limited number of observational resources. By coupling the geometric analysis of fluid parcel movement provided by the identification of Lagrangian coherent structure boundaries with high resolution, Lagrangian data assimilating numerical ocean models, we ultimately seek the accurate prediction of particle trajectories in the ocean. The overall goal is to develop a robust set Lagrangian analysis tools to provide synoptic information on the fate of drifting sensor packages.

OBJECTIVES

To develop Lagrangian analysis methods to meet the objectives of the ODDAS DRI, namely to provide launch templates for the deployment of drifting sensor platforms based on available high resolution Eulerian model data. Specifically, to determine the sensitivity of computed Lagrangian coherent structure boundaries to perturbations in the spatial and temporal resolution of input Eulerian model data.

APPROACH

Optimal deployment strategies for drifting acoustic arrays will rely heavily on precise knowledge of the location, in both time and space, of Lagrangian coherent structure boundaries computed by post-processing numerical Eulerian velocity data. A fundamental question concerning the operational use of such Lagrangian analyses is the sensitivity of the computed structures to inherent uncertainties in the model prediction of the Eulerian velocity field. Systematic analysis of the sensitivity of a number of Lagrangian statistical and geometric measures to various levels of model uncertainty will determine the model precision and fidelity needed to reliably employ LCS boundary information in an operational observational experiment. Analyses rely on the application of available Lagrangian metrics identifying particle transport pathways and statistics to velocity fields produced by high-resolution, data-assimilating circulation models.

The approach involves a fully collaborative effort with Profs. Ozgokmen, Griffa and associates at the University of Miami and CNRS, Italy as well as Profs. Kirwan, Lipphardt and associates at the University of Delaware. Model data has been kindly provided by Paul Martin of NRL, Ashwanth

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14. ABSTRACT
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Srinivasan at RASMAS and L. Kantha at University of Colorado.

WORK COMPLETED

1) Acceptance of papers documenting the sensitivity of Lagrangian structures in the context of the NCOM Adriatic model. (Haza et al., 2008), fast Lagrangian break-up of Loop Current Rings in the Gulf of Mexico (Lipphardt et al., 2008) and the role of nonlinearity and dynamical systems tools in Lagrangian ocean analyses (Kirwan et al, 2007).

2) Completion of sensitivity analysis of Lagragian Coherent Structures in NCOM model of the Adriatic.

3) Analyses of relative dispersion statistics and their dependence on model resolution in a hierarchy of ocean models (Poje et al., in preparation) including ROMS, NCOM and HYCOM.

4) Development, in collaboration with Prof. Kayo Ide (UCLA), of a parallel genetic algorithm to determine optimal launch locations for Lagrangian data assimilation.

RESULTS

(a) Analysis of Lagrangian Coherent Stuctures in the Western Adriatic Current (WAC).

Previous work (Haza et al 2008) has shown that the basin scale relative dispersion statistics in the Adriatic are controlled to a large extent by the dynamics of the thin western boundary current (WAC). We investigate the Lagrangian mixing in this region using a 1km resolution, data assimilating NCOM model from Paul Martin at NRL. Figure 1 shows the superposition of finite time unstable manifolds and surface model salinity for model data from August, 2002. For this particular time period, the LCS in the WAC reveal a pattern of cat's eye features at the inner edge of the current with the unstable sets acting as perturbed hetero-clinic connections between strongly shearing hyperbolic trajectories. The role of these Lagrangian boundaries on the advective patterns, and ultimate transport, of salinity is clear.

The lower part of the figure shows comparisons of three of the unstable manifolds computed under progressively coarser spatial smoothing of the input model velocities. Smoothing is accomplished by convolution of the full (dx = 1 km) model output with Gaussian filters with standard deviations of 2.5 and 5 km. As can be seen in the plots, organizing hyperbolic trajectories and their attending manifolds persist even under rather coarse smoothing of the vector fields. The smoothing does, however, directly reduce local velocity gradients and hence separation time scales as measured by eigenvalues of the rate of strain tensor. As such, finite time manifolds produced by the smoothed flow are shorter and significantly less foliated than those produced by the raw data. These results are consistent with the observations in Haza et al 2008. Large scale and long time Lagrangian relative dispersion statistics are dominated by identifiable hyperbolic structures in the flow that are relatively insensitive to the details of the small scale Eulerian velocity field. Spatial smoothing both reduces separation rates at small scales and extends to larger scales the exponential separation regime.

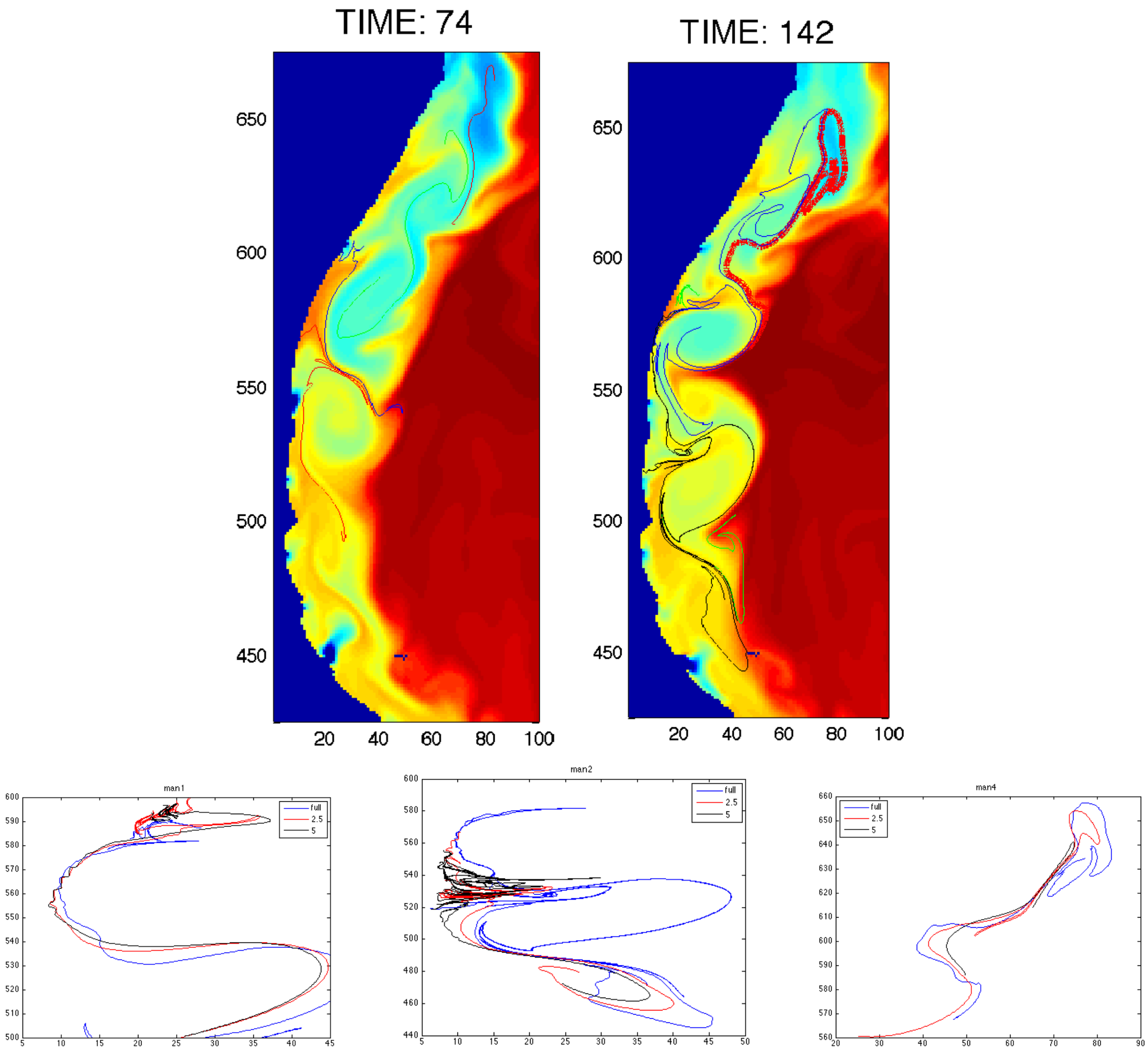

Fig. 1: Top, finite time unstable manifolds and surface salinity fields for two times, separated by ~3 days, in the western boundary region of the NCOM Adriatic model. Note the semi-regular pattern of cat's eye features revealed by the Lagrangian structures and the close correlation with the patterns of advected salinity. Below, comparison of the location and shape of three manifolds for different values of the spatial smoothing parameter. Full field in blue, 2.5 km smoothing in red, 5 km smoothing in black.

b) Scale dependent relative dispersion in a hierarchy of Ocean Models.

The effect of model resolution on the relative dispersion of particle pairs is studied using both Finite Size Lyapunov Exponent (FSLE) and maps of Finite Time Lyapunov Exponent (FTLE) measures. This is done in the context of (a) homogeneous 2D turbulence which can be smoothed in a dynamically consistent manner, (b) NCOM Adriatic simulations, (c) ROMS output of a wall bounded, baroclinically unstable jet and finally (d) high resolution HYCOM output for the North Atlantic. In each case, spatial smoothing both reduces particle pair separation rates at small separation scales and extends the range of scales where the separation rate is found to be scale independent (the exponential separation regime) as shown in Fig. 2 for temporal smoothing of the NCOM and for varying spatial resolution of the baroclinic, wall bounded ROMS simulation.

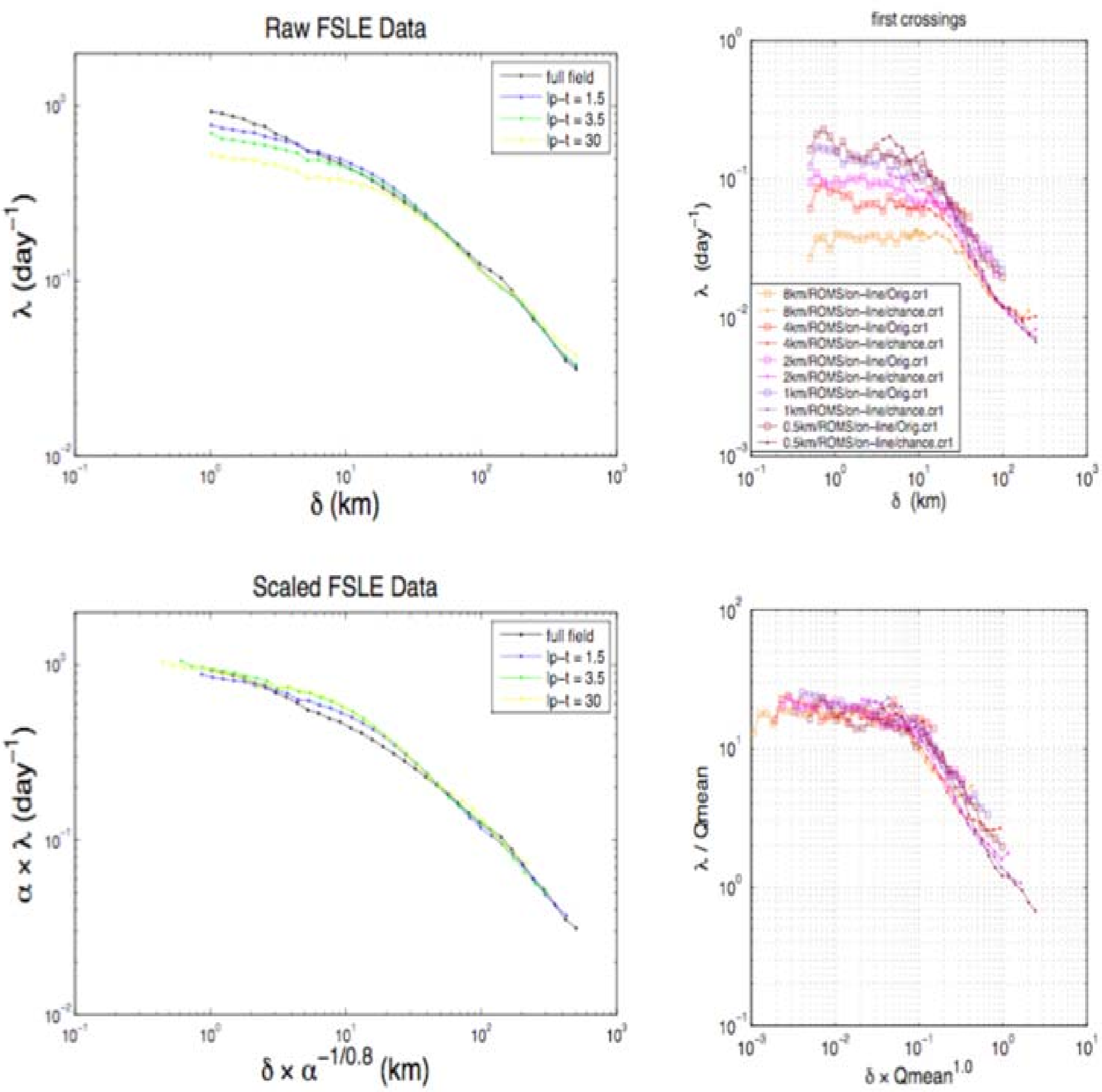

Fig. 2: Left panel, average pair separation rates versus separation distances (FSLE) for temporal smoothing of the NCOM Adriatic model. Right panel, similar plots for the wall bounded, baroclinic jet simulated in ROMS for various spatial model resolutions. Bottom plots in each panel show collapse of resolution dependence when FSLE is rescaled with 'averaged hyperbolicity' as measured by spatial average of positive Okubo-Weiss parameter.

Simple arguments for limiting small values of pair separation indicate that the value of the particle pair separation rate in the exponential regime depends primarily upon the model's resolution of velocity gradients, specifically gradients in strongly hyperbolic, inter-eddy regions. As shown in the bottom of both panels in Fig. 3, computed time to distance graphs (FSLE) show very good collapse when the data is normalized by the average value of the positive (hyperbolic) Okubo-Weiss parameter, Q.

c) Genetic Algorithms for locating optimal launch locations for Lagrangian data assimilation.

Using the augmented state space Lagrangian data assimilation scheme of Ide and Jones (Ide et al 2005), we have developed an optimization scheme based on genetic algorithms (GA), which is capable of exploring the extremely high dimensional search space of initial drifter locations to find those locations which lead to the most accurate assimilation results. The GA, a classically *embarrassingly parallel* search algorithm, has been implemented on the local 496 node computational cluster. As a preliminary test, we consider the chaotic flow induced by the mutual interaction of five point vortices and attempt to locate both the centroid position and alignment angle of the three particle pairs which produce the most accurate assimilation of the five vortex positions in time. As shown in Fig. 4, optimal locations are consistent with the Lagrangian Coherent Structure based directed launch strategies proposed by Salman et al. 2007, Molcard et al. 2006 and Poje et al. 2003.

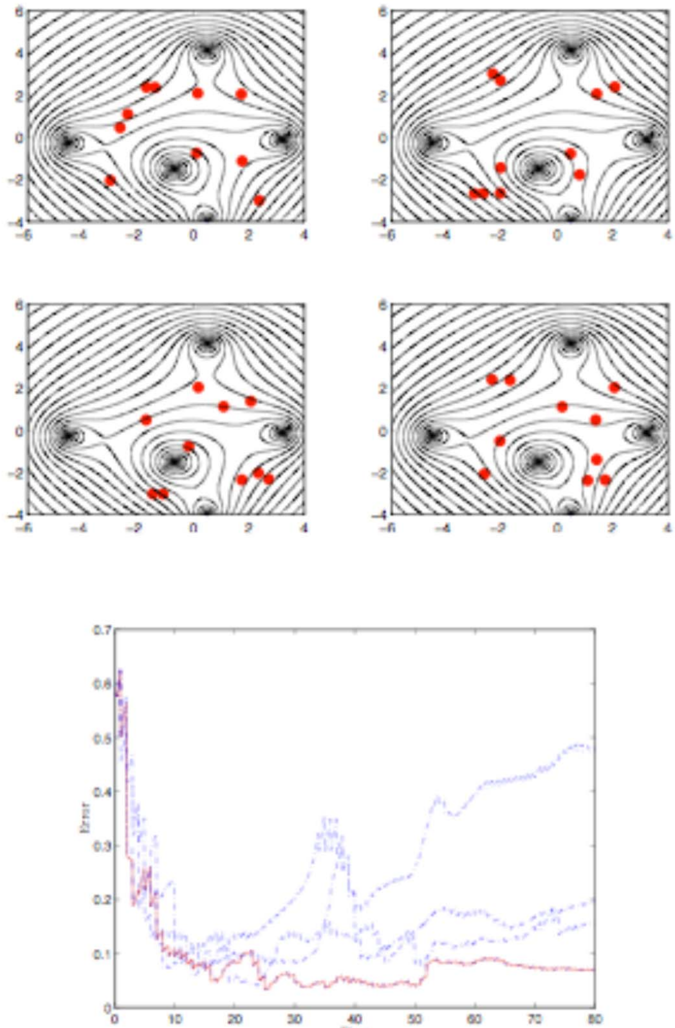

Fig. 3: Top, four sets of assimilation-optimal launch locations of 10 particles in the point vortex flow as determined by a parallel Genetic Algorithm. Below, assimilation error, defined as the mean difference between assimilated and model vortex positions, for the four sets of initial conditions.

IMPACT/APPLICATIONS

The combined use of Lagrangian structure metrics in conjunction with high-resolution, realistic coastal circulation models has been shown to be a feasible approach to the design of real-time directed drifter launch protocols in actual observational programs.

The separation scales where FSLE fields are found to be robust to model uncertainty at the smallest time and space scales have been identified in a number of ocean models of naval relevance. A connection between the behavior of small scale separation rates and Eulerian model resolution is given in terms of model gradient resolution via averages of hyperbolicity as measured by Okubo-Weiss measures.

RELATED PROJECTS

Theoretical and numerical tools developed under this effort will directly inform research on constructing flow-based control algorithms for autonomous ocean surveillance and observation systems funded under ONR Grant N000140710588, PI Poje.

The work described here is part of a continuing collaborative effort and intersects with:

Predictability of particle trajectories in the ocean, ONR, PI: T.M. Özgökmen, N00014-05-1-0095.

Model Assessment and Deployment Strategies for Drifting Instruments, ONR, PI: A.D. Kirwan, N0014-00-0019

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

PUBLICATIONS [refereed]

Haza, A. C., A.C. Poje, T. M. Ozgokmen and P. Martin, Relative dispersion from a high-resolution ocean model: of the Adriatic Sea. *Ocean Modeling*, **22**, p48-65, 2008.

Lipphardt, B.L., A.C. Poje, A.D. Kirwan, L. M. Zweng, & , L. Kantha, Sudden Death of Loop Current Rings in a Gulf of Mexico model. *Journal of Marine Research*, **66**, p25-60, 2008.

A.D. Kirwan B.L. Lipphardt Jr, A.C. Poje , L. Kantha and M. Zweng, 25 Years of Nonlinearity in Oceanography from the Lagrangian Perspective in *Nonlinear Dynamics in Geosciences*, Springer, (2007)