Merging Disparate Data and Numerical Model Results for Dynamically Constrained Nowcasts

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LONG-TERM GOALS

Our long-term goal is to quantify submesoscale dynamical processes in the ocean so that we can better understand their interactions with motions at larger scales. In particular, we focus on the following four areas:

- Small-scale coastal process studies;
- Understanding small-scale advective exchange and stirring;
- Model assessment, enhancement, and assimilation;
- Use of high-resolution disparate (HRD) ocean surface data to infer subsurface flow conditions.

OBJECTIVES

Our objective is to develop dynamically consistent nowcasts of the surface velocity field by combining disparate observations from sensors like HF radar, Lagrangian drifters, current meters, ADCPs and passive remote sensing. When needed, open boundary flow information from any source (observations, models, climatology, etc.) is used. The nowcasts can be analyzed to understand coastal processes, to infer aspects of the subsurface flow, or to assimilate into a numerical model. Recently developed dynamical systems templates can also be used to study the mixing characteristics of the nowcast field.

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APPROACH

To develop a surface velocity nowcast from disparate data, we use a spectral technique called normal mode analysis (NMA) which is a generalization of a method first described by Rao and Schwab (1981) in an analysis of currents in Lake Ontario. The NMA method relies on numerically generated basis function sets of both vorticity and divergence modes to represent the data. It is described by Eremeev *et al*. (1992a), and a number of oceanographic applications are discussed in Eremeev *et al.* (1992b), Eremeev *et al*. (1995a,b), Lipphardt *et al*. (1997) Cho *et al.* (1998), and Lipphardt *et al.* (2000). This approach has several attributes which make it well suited for coastal ocean studies, including rapid environmental assessment situations:

- Its spectral character readily admits data from disparate sources;
- Any arbitrarily shaped domain can be analyzed;
- The spatial basis set can be calculated to arbitrary accuracy independent of the data;
- Open boundary information from any source can be easily blended with observations;
- The nowcast velocity field is three-dimensionally incompressible.

WORK COMPLETED

Work on our first proposed task (generating nowcasts from HF radar observations and numerical model open boundary flow) is complete, and the results have been published (Lipphardt *et al.*, 2000). We have continued developments related to this task by generalizing the nowcast scheme in Monterey Bay, using HF radar data supplied by Jeff Paduan at the Naval Postgraduate School, so that we can now produce surface velocity maps using only the HF radar observations, with no requirement for model data.

Work on our second proposed task (assessment of a numerical model of a semi-enclosed sea) has progressed in parallel with a related ONR funded DRI effort on *Enhanced Ocean Predictability Through Optimal Observing Strategies*. Results from a Gulf of Mexico model run by Lakshmi Kantha's group at the University of Colorado have been compared with a number of observed Lagrangian drifter trajectories in the deep Gulf of Mexico during the last half of 1998. We have demonstrated that NMA can be used successfully to combine observed Lagrangian flow information with the model surface velocity field.

Work on our third proposed task (nowcasts of Gulf of Mexico surface currents from disparate observations and a forecast model) was completed in 1999 and published in a dissertation by LCDR William Schulz (Schulz, 1999). His dissertation described a method for combining Lagrangian drifter observations, current meter observations, and results from the Navy's Modular Ocean Data Assimilation System (MODAS) model to nowcast the surface velocity field on the Louisiana-Texas shelf. We have continued development of his techniques, and we are exploring some ideas for improved spatial and temporal filtering, as well as alternate approaches to handling flow along the large open boundary segments.

We have also continued collaborative work with Steve Wiggins' group at Caltech on an emerging task area: studies of small-scale advective exchange and stirring in the coastal ocean. The Caltech group has successfully applied newly developed dynamical systems templates to our NMA mapped surface velocity field (using *only* HF radar observations) to identify transport alleyways and flow boundaries for early August 1994. A manuscript describing these results is currently under review.

RESULTS

We can now routinely nowcast the surface velocity, vorticity, and divergence fields from HRD data for domains with large open boundary segments using NMA. In some cases, like the recent work in Monterey Bay, observations alone are enough to constrain the nowcast, even when the domain contains open boundaries. NMA nowcasts are particularly useful for analyzing coastal regions observed by HF radar, since the size of the radar footprint varies with time, and often contains spatial gaps. As an example, figure 1 shows the observed HF radar velocities in Monterey Bay for 0100 UT, 6 August 1994 (left) and the spatially filtered velocity field for the same time (right) using 19 NMA modes.

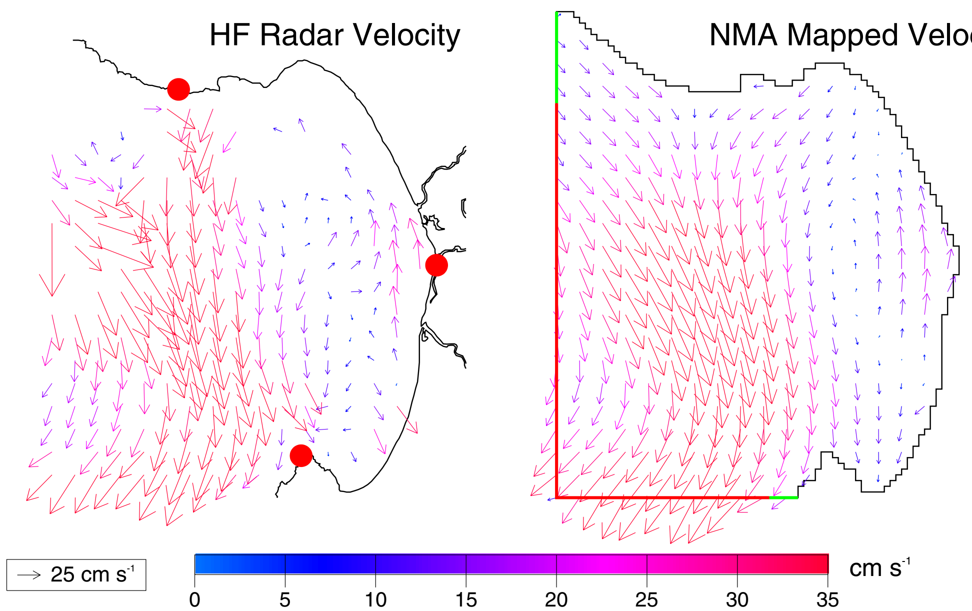

Figure 1: Observed HF radar velocities for 0100 UT, 6 August 1994 (left) and the spatially filtered 19 mode NMA velocity field for the same time (right).

Since the NMA mapped field is fully dense, dynamical systems templates can be readily applied. Figure 2 shows six daily positions of two parcels released at the same location in Monterey Bay during August 1994. The magenta parcel was released at 0130 UT on 2 August and most of it will

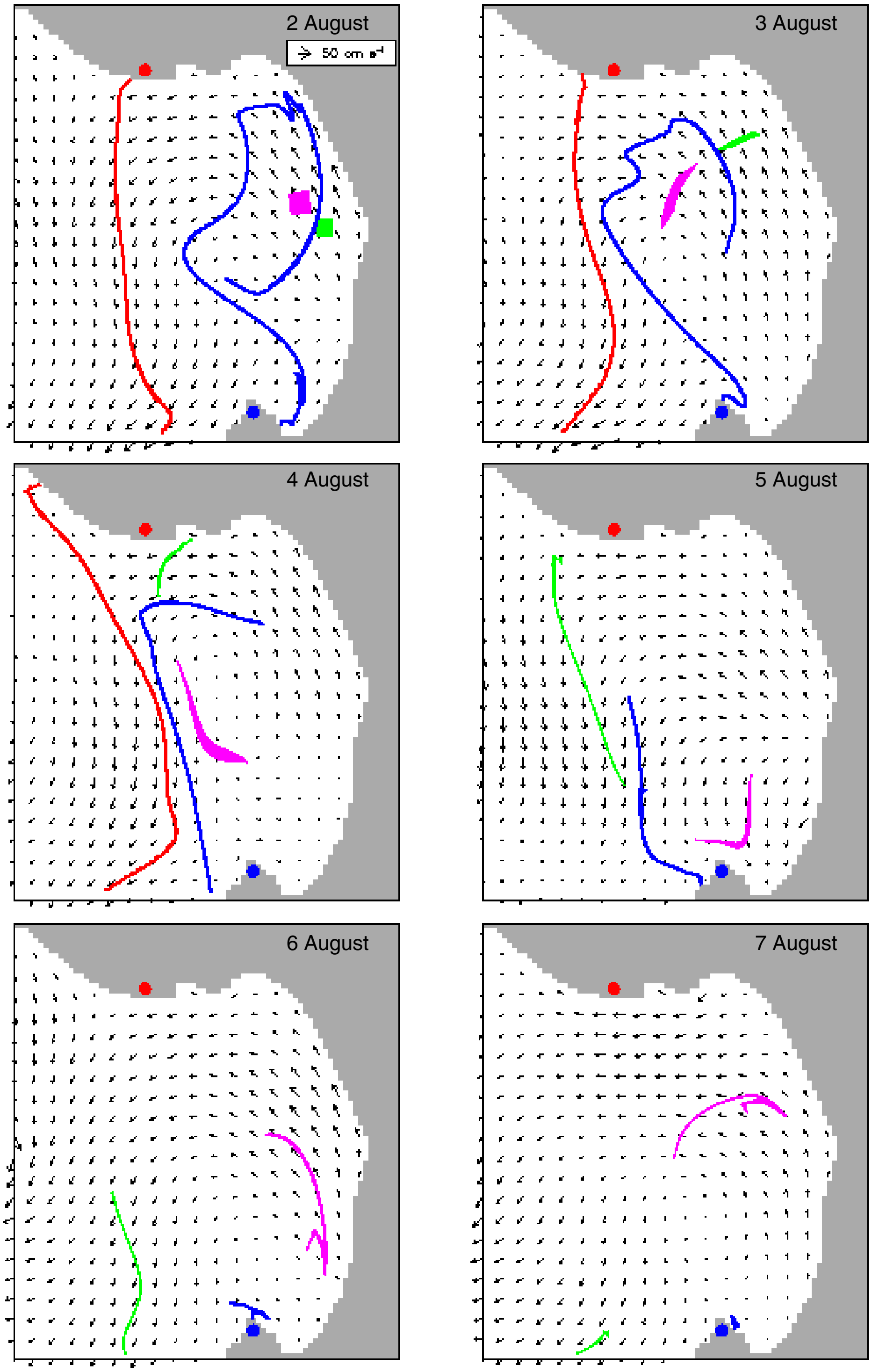

Figure 2: Daily positions of two fluid parcels in Monterey Bay for 0430 UT on the date shown at upper right of each panel. The blue and red curves show the stable and unstable manifolds, respectively. A Quicktime animation of these results can be viewed on the World--Wide Web at http://transport.caltech.edu/animations/august94.mov.

remain in the bay even after 17 August. The green parcel has just been released (three hours after the magenta parcel), and it will leave the bay entirely at 1200 UT, 7 August.

Dynamical systems theory identified the stable and unstable invariant manifolds, shown as blue and red curves, respectively, in figure 2. Since invariant manifolds are material surfaces, in the absence of molecular diffusion they are impenetrable boundaries for fluid parcel trajectories. By noting the shape and location of the manifolds (which evolve in time), we can understand the dramatic difference in the evolution of the two fluid parcels. The first parcel is released just to the left of the stable manifold, and the second parcel is released just to its right, so the second parcel will leave the bay as it reaches Point Pinos, whereas the first parcel will turn eastward and reenter the bay.

The stable and unstable manifolds form a time varying alleyway that governs transport processes in the bay. All of the transport into and out of the bay must occur near Point Pinos, where the transport alleyway opens to the west. The persistence of the unstable manifold prevents transport into or out of the bay near Santa Cruz (shown as a red circle near the top of each panel in figure 2) during this time period. Understanding the transport associated with surface currents in Monterey Bay, then, comes from an understanding of the geometry of the stable and unstable manifolds.

IMPACT/APPLICATIONS

The utility of NMA for blending HRD data in a dynamically consistent way has been demonstrated in a number of different ocean applications. It can be applied to a wide variety of data using any grid at any resolution; it ensures three dimensional incompressibility; and it naturally incorporates traditional boundary conditions. Our recent published results (Schulz, 1999; Lipphardt *et al.*, 2000) demonstrate the utility of the method for a rapid environmental assessment situation.

TRANSITIONS

Our recent published results (Schulz, 1999; Lipphardt *et al.*, 2000) represent the first steps toward transitioning the NMA method to operational use as a REA tool.

RELATED PROJECTS

An ONR DRI entitled *Enhanced Ocean Predictability Through Optimal Observing Strategies* provides us with additional support to study the dynamical systems characteristics of ocean flows and to develop optimal sampling strategies for these flows. As part of this work, we have used the NMA method to study sampling strategies for a basin scale model of a double gyre. This work has been documented in a manuscript that is currently under review.

We also continue to collaborate with scientists from Caltech, the Naval Postgraduate School, the University of Colorado, and Ocean Physics Research and Development to analyze HF radar and model data, and to study mixing processes in the coastal ocean.

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