Dynamically Constrained Nowcasting in the Coastal Ocean

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LONG-TERM GOALS

Our long-term goal is to quantify submesoscale processes in order to improve our understanding of ocean interactions at various space and time scales. Our current effort focuses on the following four tasks:

1. Understanding small-scale coastal ocean processes;

2. Understanding small-scale advective exchange and stirring;

3. Model assessment, enhancement, and assimilation;

4. Using 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 a variety of sensors, including HF radar, Lagrangian drifters, current meters, ADCPs, and passive remote sensing. We can incorporate normal flow information at open boundaries from any source (observations, models, climatology, etc.).

These nowcasts can be used to study the evolution of coastal processes including mixing and exchange. When assimilated into a numerical model, the nowcasts can also be used to infer aspects of the subsurface flow.

APPROACH

Our nowcasts employ an objective mapping technique that is a generalization of a method first described by Rao and Schwab (1981) in an analysis of currents in Lake Ontario. The technique, called normal

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14. ABSTRACT
Our objective is to develop dynamically consistent nowcasts of the surface velocity field by combining disparate observations from a variety of sensors, including HF radar, Lagrangian drifters, current meters, ADCPs, and passive remote sensing. We can incorporate normal flow information at open boundaries from any source (observations, models, climatology, etc.).

15. SUBJECT TERMS

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mode analysis (NMA) uses numerically generated sets of vorticity and divergence basis functions to blend disparate surface velocity information into a dynamically constrained nowcast. The NMA method is described by Eremeev *et al*. (1992a), with oceanographic applications discussed in Eremeev *et al.* (1992b), Eremeev *et al*. (1995a,b), Lipphardt *et al*. (1997), Cho *et al.* (1998), Lipphardt *et al.* (2000), Schulz (1999) and Hunter (2001). This method has several attributes which make it attractive for coastal ocean studies and rapid environmental assessment situations:

- Its spectral character readily admits data from disparate sources;
- Any arbitrarily shaped domain (including islands) 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

Study of small-scale processes in Monterey Bay surface currents for June 1999 through January 2000 has motivated several improvements in our approach to NMA mapping of HF radar observations. We have developed a bootstrap approach to mapping the observations which relies on a low-mode mapping to supplement the observations in regions where spatial gaps occur. In addition, we have developed an algorithm which identifies and removes "outliers" in the observation set. An outlier is defined as any observation that exceeds a maximum specified kinetic energy difference threshold when compared with a reference NMA mapping. Removing outliers typically adds 6-8% to the total observed kinetic energy accounted for by an NMA mapping. We have also implemented a tidal current analysis algorithm (Foreman, 1978) which we use to fill temporal gaps in HF radar observations along the mapping domain open boundary and to compare the tidal characteristics of the observed and mapped surface velocities. Improvements in the algorithm we use to calculate velocities on the domain boundary have allowed us to compute line integrals around the mapping boundary, yielding estimates of net outflow and circulation. Finally, we have used wavelets to identify several energetic oscillations with periods of 5-15 days in the radar observations that are well correlated with the north-south component of surface wind measured near the center of the mapping domain.

We continue to collaborate with the Steve Wiggins group at the University of Bristol and Kayo Ide at UCLA to study surface transport and mixing in Monterey Bay. We supply surface velocity nowcasts to the Wiggins group, who then integrate large numbers of simulated Lagrangian particles to measure escape times from the mapping domain. We use two classes of escape events: escape to the open ocean, or encounter with the coast. This distinction between escape fates has revealed rich time dependent structure in the surface velocities in the bay.

Work on the remaining two tasks has focused on improving the ability to assimilate radar observations into a regional numerical model. We are working with Igor Shulman at the University of Southern Mississippi to use NMA to extend error covariances from the radar footprint to cover the entire model domain. This has proven to be quite challenging, since the radar footprint area represents only a small fraction of the model's surface area.

RESULTS

Figure 1 shows time series of net outflow and circulation for Monterey Bay during August 1994 computed as a line integral of normal or tangential NMA mapped velocities around the domain boundary shown in green in each panel of figure 2. Mean values for each time series are shown in green in figure 1. During this period, there was net outflow and a net positive circulation in the bay.
The net outflow suggests that there was a compensating net subsurface inflow.

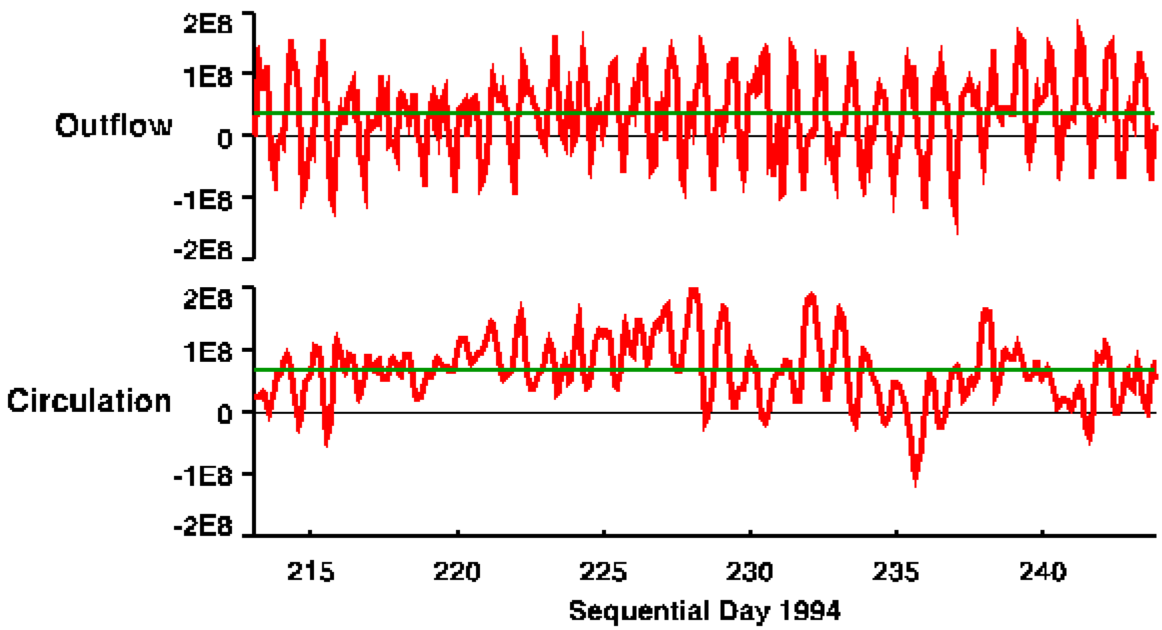

Figure 1: Time series of outflow and circulation around the perimeter of Monterey Bay for August 1994. Units are cm^2 s^{-1}. Mean values are shown as green lines. Both time series show diurnal oscillations. Monthly mean values indicate net outflow and net positive circulation for the bay.

Outflow and circulation are important integral constraints for dynamical studies since they are related through Green's and Stokes' theorems to the area integrals of horizontal divergence and vorticity by

$$Outflow = \oint_B \vec{u} \bullet \hat{n}\ dS = \iint_A \nabla \bullet \vec{u}\ dA$$

$$Circulation = \oint_B \vec{u} \bullet \hat{t}\ dS = \iint_A \nabla \times \vec{u}\ dA$$

where $\hat{n}$ and $\hat{t}$ are the normal and tangential unit vectors along the boundary, respectively.

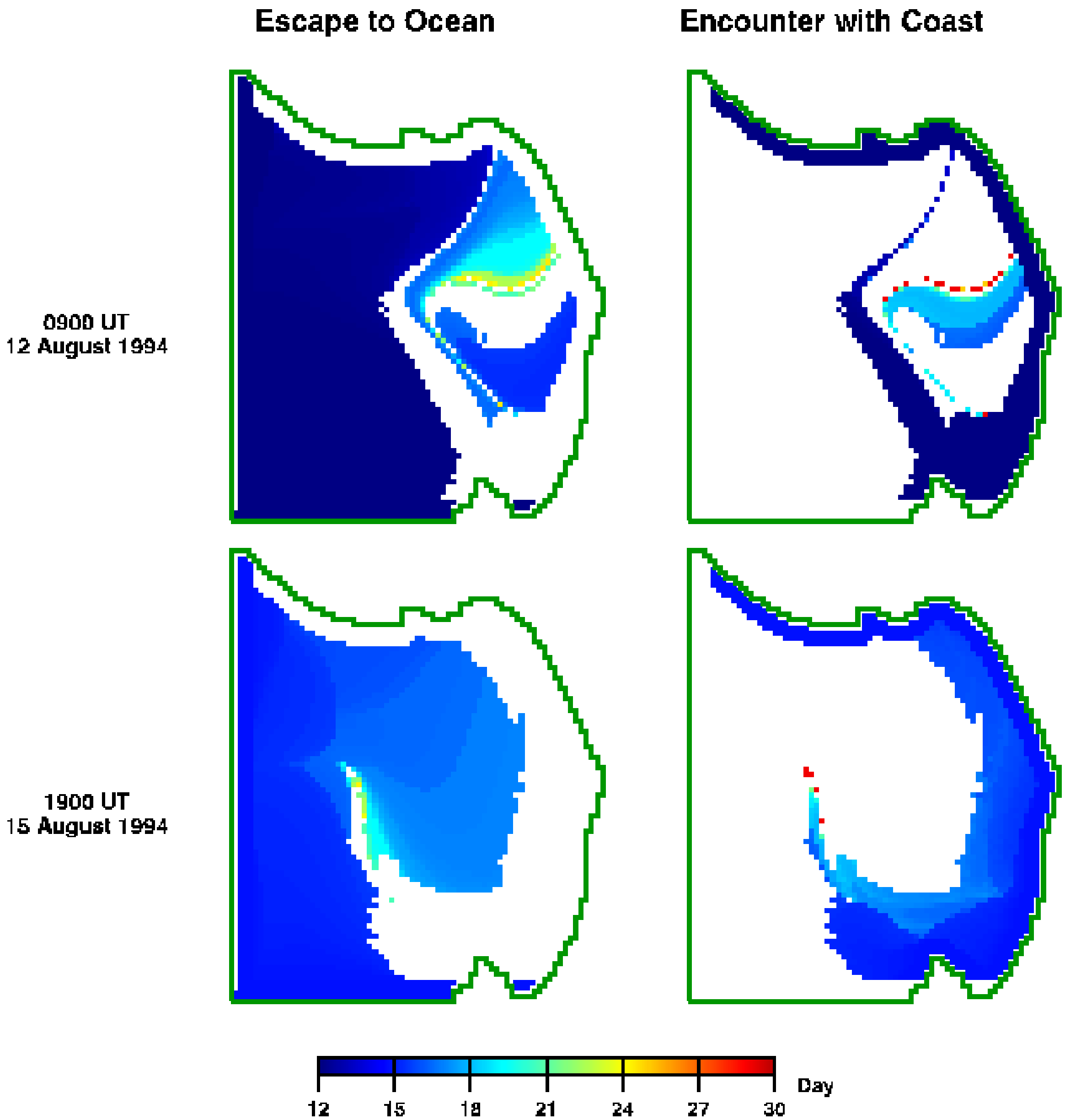

Figure 2: Escape time maps for particles launched on 0900 UT, 12 August 1994 and 1900 UT, 15 August 1994 based on an NMA nowcast of surface velocity in Monterey Bay. Color pixels represent individual simulated Lagrangian particles color coded to show the time/date that they escape the domain. Left panels show particles that escape to the open ocean. Right panels show particles encountering the coast. The maps for 12 August show a complex, filamentous spatial pattern. The 15 August maps show spatial coherence over much larger scales. Both sets of maps show the majority of particles escaping to the open ocean.

Figure 2 shows escape time maps for 0900 UT, 12 August 1994 and 1900 UT, 15 August 1994 calculated from an NMA mapping of Monterey Bay surface velocities for August 1994. Escape times for 12 August show a complex filament structure inside the bay while the maps for 15 August show coherent patches at much larger spatial scales. For this calculation, we define a coastal encounter as any particle that passes within 2 km of the coastline. Particles are said to escape to the open ocean if the pass within 2 km of the open boundaries at the west or south.

IMPACT/APPLICATIONS

We have demonstrated that the NMA technique is computationally inexpensive and can be applied to a wide variety of disparate data sets. It naturally enforces three-dimensional incompressibility and appropriate boundary conditions, making it an attractive choice for many rapid environmental assessment situations.

TRANSITIONS

The involvement of graduate students in this research effort has proved to be an excellent way to begin transitioning the NMA technique for wider use. Two graduate students completed their degrees while pursuing research related to this effort. LCDR William Schulz completed his PhD dissertation in 1999 and studied surface currents on the Louisiana-Texas shelf using NMA (Schulz, 1999). Eli Hunter completed his M.S. thesis by extending the Schulz 1999 work, examining the mixing and exchange characteristics of the Louisiana-Texas shelf surface velocity field (Hunter, 2001).

RELATED PROJECTS

There is considerable interaction with an ONR supported DRI entitled *Enhanced Ocean Predictability Through Optimal Observing Strategies*. That effort uses the NMA methodology to explore sampling strategies on a regional ocean scale using templates based on dynamical systems theory. We have access to a state of the art Gulf of Mexico model and concurrent drifter data. The drifters are used for model assessment.

Our recent progress has also relied heavily on close collaboration with Jeff Paduan at the Naval Postgraduate School, Steve Wiggins and his group at the University of Bristol, Kayo Ide at UCLA, and Igor Shulman at the University of Southern Mississippi.

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