Enhanced Ocean Predictability Through Optimal Observing Strategies

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LONG-TERM GOALS

The long-term goals of this research are to develop the requisite technology to design effective observation strategies that will maximize the capacity to predict mesoscale and submesoscale conditions so as to understand the physical processes responsible for these conditions and to provide the best possible now-casts and forecasts of oceanic conditions.

OBJECTIVES

There are three tightly integrated objectives. The first is to focus both oceanographic and dynamical systems approaches on developing optimal observing strategies. The common thread linking both approaches is Lagrangian analysis, and so this phase of the work addresses the question of how best to utilize Eulerian current maps constructed from disparate data and how to use the information contained therein to design optimal observing systems.

The second objective will be to design an optimal observing strategy from a synthetic database. Here we will use primitive equation model simulations as the control. The last objective will be to apply this technology to the Gulf of Mexico where both high-resolution numerical model results and drifter data are available.

APPROACH

We approach the objectives in this effort by combining the oceanographic methodology of objective Eulerian current reconstruction initiated by Rao and Schwab (1981), Eremeev *et al.* 1992 and Chao *et al.* 1998 with dynamical systems techniques of invariant manifold calculations as presented in Poje and Haller (1999). During the first phase of the study, we shall utilize model flows where the Lagrangian

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dynamics are known. Analysis methodologies developed from prior ONR supported research will be applied to flows so as to establish benchmark cases for testing observation. The second phase will apply the methodology to a natural oceanographic setting. Due to the availability of relevant data and models, this phase will focus on the Gulf of Mexico.

WORK COMPLETED

The emphasis during the first year was on the first objective. In fiscal year 1999, practical aspects involved in the reconstruction of Eulerian velocity fields from Lagrangian data were addressed. A major result was quantifying the effect drifter coverage (in particular data voids) has on the accuracy of the Eulerian velocity reconstruction. A reduced gravity, double gyre primitive equation model was used for that effort.

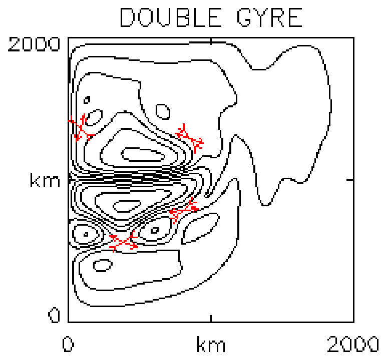
During fiscal year 2000, progress was made on all three objectives. An optimal observation strategy was identified for the double gyre model, which makes significant progress on the first two objectives. A high resolution Gulf of Mexico model and drifter data were analyzed using both the dynamical systems and NMA methods, an essential component of the third objective.

The optimal observation strategy involves identifying launch sites that achieve maximum dispersion, so as to improve drifter coverage. Frozen-time stagnation points, under the appropriate flow criteria, approximate these launch locations.

Analysis of the Gulf of Mexico model with drifter data involved two approaches. First, the NMA methodology allowed the model and drifter data to be merged to improve the accuracy and predictability of numerical trajectories. Second, a finite time invariant manifold technique culled from dynamical systems theory was used to delineate the boundaries of coherent structures. The relation of the drifters to these boundaries provide a new model assessment tool.

RESULTS

Frozen-time, saddle-type stagnation points for the double gyre model are shown in Figure 1. The eigenvectors associated with positive eigenvalues are shown pointing away from the stagnation point and indicate the local direction of the unstable manifolds. Maximum dispersion occurs in this direction at a local rate determined by the positive eigenvalue. Similarly, eigenvectors associated with negative eigenvalues (shown pointing toward the stagnation point) indicate the local direction of the stable manifolds. Figure 2 shows the dispersion rates of simulated drifters launched at these sites verses drifters launched at random locations.



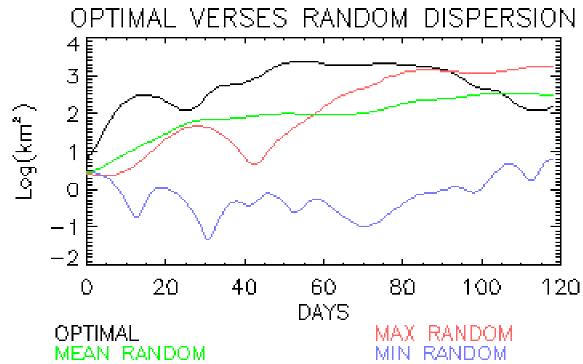
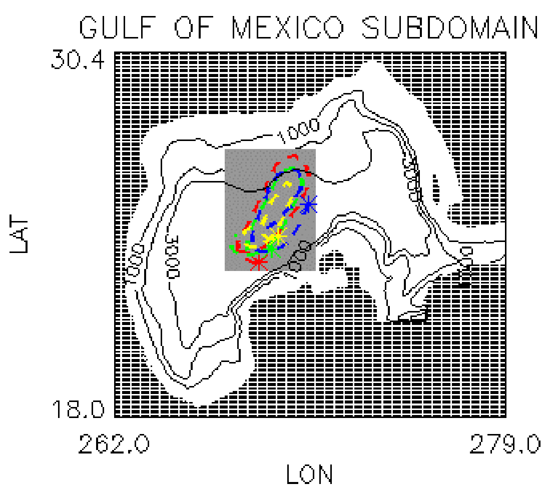


Figure 1. (left) Fixed-time stagnation points with saddle character determine the optimal dispersion launch sites at a particular time.

Figure 2. (right) Comparison of dispersion time series for drifters launched at random locations and drifters launched at optimal sites. Dispersion is only optimal early in the time series since the drifters move away from the launch sites.

Since the test case for the third objective is the Gulf of Mexico, an assessment of model performance in relation to drifter data was paramount. One assessment involved four drifters from the subdomain in Figure 3 that were used to analyze the model velocity at 50m, the drogue depth for the drifters. A velocity field was constructed that merged model and drifter data in the subdomain. This merged velocity field did not differ from the model by more than 10%, yet produced more accurate numerical trajectories than the model field. These results are summarized in Figure 4.



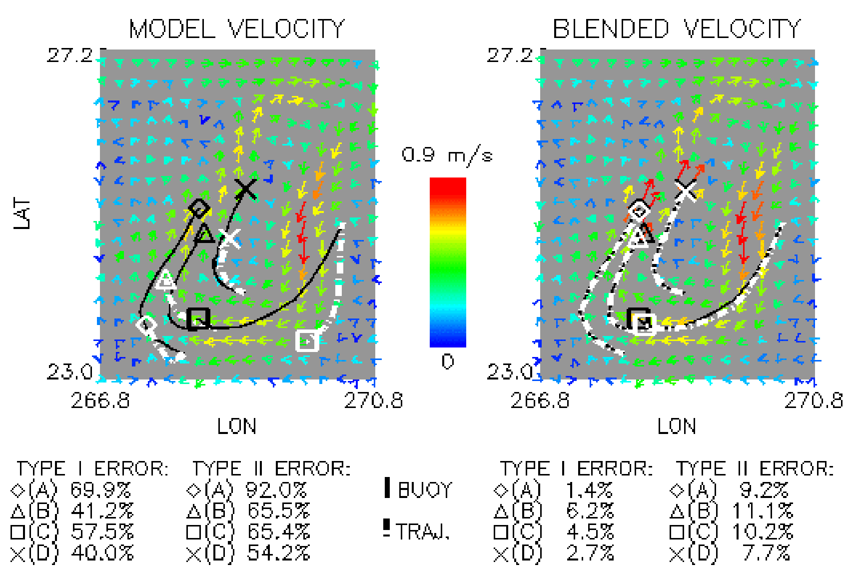


Figure 3. (left) Subdomain and 20 day drifter tracks in the Gulf of Mexico used for trajectory comparison.

Figure 4. (right) Comparison of numerical trajectories (white) and real drifter paths (black) for the model and blended velocity fields. Type I and Type II errors are position and shape errors respectively.

A second assessment involved the computation of finite-time invariant manifolds from the model velocity at 50m in the eastern Gulf and comparison of the resulting geometry with drifter paths. The manifolds give the boundaries of the Lagrangian coherent structures as determined from the model velocity. There is good agreement between the manifold geometry and the TOPEX/Poseidon/ERS-2 altimetry data. The drifter data indicates general circulation features that agree with the model, although the drifters respond to physics not included in the model. Figure 5 shows the orientation of manifolds and drifter positions superimposed on the altimetry data at one time slice of the analysis. Note that the manifolds clearly distinguish four coherent structures: a large Loop Lurrent ring (to the west), a small cyclone between this ring and the Loop Current, a ring pinching from the northward meander in the Loop Current, and a stationary Tortugas cyclone.

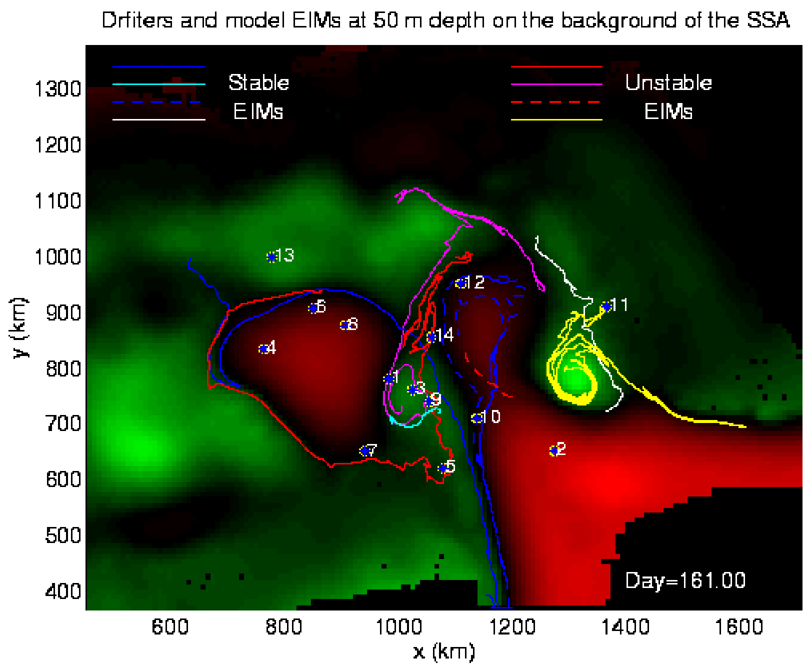


Figure 5. Finite time invariant manifolds delinate the boundaries of coherent flow structures in the eastern Gulf. Fourteen drifters in the region qualitatively agree with the manifold pattern. The background is altimetry data with red and green indicating positive and negative sea surface anomalies respectively. The southern portion of the figure depicts Cuba on the right and Yucatan on the left.

IMPACT/APPLICATIONS

The immediate application of this technology will be to Rapid Environmental Assessment (REA). In addition to the traditional military interest in REA, civilian applications in environmental crisis management, ranging from pollution monitoring and containment to risk assessment for hazardous waste operations, will increase substantially in the next few years.

Results obtained thus far are generic in that the spatial coverage and comparative quality issues of the Lagrangian data apply to open and arbitrarily shaped domains. Our results on dispersion in the double gyre and coherent structures in the Gulf of Mexico are applicable to all regions in the world ocean.

TRANSITIONS

The methodology in this study will be used to assess the predictive capability of a high resolution Princeton Ocean Model (POM) of the Gulf of Mexico in a collaborative effort with Lakshmi Kantha at the University of Colorado. Additionally, this methodology was used in a Ph.D. dissertation by LCDR William Schultz titled, "Ocean Surface Maps from Blending Disparate Data through Normal Mode Analysis," at Old Dominion University. In this effort, MODAS was used in combination with NMA to provide nowcasts of the Texas-Louisiana Shelf with drifter and mooring data.

RELATED PROJECTS

The nowcast technology is being utilized to investigate HF radar data, provided by Jeff Paduan at the Naval Postgraduate School, in Monterey, CA through another ONR project N00014-99-1-0052.

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