Enhanced Ocean Predictability Through Optimal Observing Strategies

A. D. Kirwan, Jr.
College of Marine Studies, University of Delaware, Newark, DE 19716
Phone: (302) 831-2977 Fax: (302) 831-6838 email: adk@udel.edu

Michael S. Toner
College of Marine Studies, University of Delaware, Newark, DE 19716
Phone: (302) 831-1175 Fax: (302) 831-6838 email: toner@.udel.edu

Award Number: N00014-00-1-0019
http://newark.cms.udel.edu/~brucel/hrd.html

LONG-TERM GOALS

The long-term goal of this research is to develop the requisite technologies for effective observation strategies that provide the best possible now-casts and forecasts of oceanic conditions. This research contributes to the effort to predict mesoscale and submesoscale conditions and to understand the physical processes responsible for these conditions.

OBJECTIVES

Three tightly integrated objectives form the goal of this research: integrating Lagrangian methods from dynamical systems into oceanographic applications, designing an optimal observing strategy based on these methods, and applying the results to data assimilating ocean models. Since the focus is Lagrangian data, the later two objectives are slanted towards optimal drifter deployment. The Gulf of Mexico primarily is used in this effort because both high-resolution numerical model results and drifter data were available.

Ultimately, these three objectives will lead to a cumulative understanding of how drifter deployments may be used in conjunction with coherent features in the ocean, such rings and eddies, to understand how their Lagrangian boundaries effect advection. This Lagrangian data provides crucial information unavailable with Eulerian estimations of the ocean state.

APPROACH

Objective Eulerian current reconstruction initiated by Rao and Schwab (1981), Eremeev et al (1992) , Chao et al (1998), and Lipphardt et al (2000) as well as Lagrangian methods using material curves to delineate coherent flow features presented in Poje and Haller (1999) form the core approach. The Eulerian reconstruction methods result from prior ONR support. The research here focuses on how the material curve analysis may be applied to ocean flow, specifically data assimilating GCMs. This analysis results in a Lagrangian flow template which is then combined with the objective reconstruction methods to optimally sample the ocean state.

Report Documentation Page	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE **30 SEP 2002**	2. REPORT TYPE	3. DATES COVERED **00-00-2002 to 00-00-2002**

4. TITLE AND SUBTITLE **Enhanced Ocean Predictability Through Optimal Observing Strategies**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **College of Marine Studies, University of Delaware,,Newark,,DE, 19716**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The long-term goal of this research is to develop the requisite technologies for effective observation strategies that provide the best possible now-casts and forecasts of oceanic conditions. This research contributes to the effort to predict mesoscale and submesoscale conditions and to understand the physical processes responsible for these conditions.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**8**	

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. See Toner et al (2000). A reduced gravity, double gyre primitive equation model was used for that effort.

In the second year, progress was made on all three objectives. During fiscal year 2000, a deployment strategy that produced optimal dispersion was identified for the double gyre model, which represented significant progress on the first two objectives. Additionally, high resolution Gulf of Mexico model and drifter data were analyzed using both the dynamical systems (Kuznetsov et al, 2002) and objective mapping methods (Toner et al, 2001), an essential element of the third objective.

During the third year, FY 2001, the optimal deployment strategy was applied to a double gyre model (Poje et al, 2002), the effect uncertainty in the Eulerian flow has on the Lagrangian analysis was investigated (Kuznetsov et al 2002), and a data assimilating Gulf of Mexico ocean model was used to test how the methods work in a natural flow.

Crucial elements of the Lagrangian methods used for the optimal deployment were implemented during FY 2002, which resulted in a new understanding of advection in the Gulf. Considerable effort was spent in developing software for constructing the special material curve that delineate features such as rings and eddies. It was discovered that the advection paths in the Gulf are dominated by inter-eddy channels, the boundary of which correspond to the material boundaries of adjacent eddies and rings. See Kirwan et al (2002). These inter-eddy paths were corroborated using ocean color as a "tracer of convenience" with which the Lagrangian analysis of the data assimilating ocean model was compared. See Toner et al (2002). This result corroborated both the model and method, and lead to the design of an advection prediction experiment.

RESULTS

The optimal observation strategy involves identifying launch sites based on the location of hyperbolic trajectories to improve drifter coverage. In idealized flow, Eulerian stagnation points shadow these trajectories, but this approach is not feasible for realistic ocean flow. Short-term (3-4 day) Lagrangian maps, however, provide more information and are not subject to erroneous high frequency temporal fluctuations. These maps provide the data to compute a spatial map of two-particle dispersion, also known as finite-time Lyapunov exponents (Haller, 2001; Lapeyre, 2001) which can identify hyperbolic trajectories reliably.

Upon computing appropriate material curves to delineate coherent features in the Gulf, complicated advection patterns were uncovered. In particular, significant inter-eddy advection was found to take place on much shorter time frames than intra eddy translation.

To document this inter-eddy advection, SeaWiFS ocean color data was used as a "tracer of convenience" in conjunction with the data assimilating ocean model. See Toner, et al (2002). On April 17, 1998 (Figure 1), a large cyclone adjacent to the Loop Current advects chlorophyll-enriched water between the Yucatan and southern West Florida Shelf. Material curves from two hyperbolic trajectories are used to delineate the boundaries of the Loop Current and this cyclone. Note that the chlorophyll plume between the Yucatan Shelf and the southern West Florida Shelf follows the advective channel between the outflowing material curve (red) of B-2 and the inflowing material curve (blue) of B-1. The mushroom shape in this chlorophyll plume near B-1 is typical of tracers advected towards a hyperbolic trajectory. It is very common for material curves emanating from one hyperbolic trajectory to merge with or intersect material curves from another, thus causing “kinks”. This is a typical feature found in data assimilating GCMs that does not exist in idealized ocean flow.

Simulated drifter launches indicate how the Lagrangian template can explain drifter behavior. Three days after simulated drifters are launched around B-1, one group follows the northern boundary of the Loop Current while the other group heads toward the other hyperbolic trajectory B-2. Two days after their launch around B-2, one group of drifters travel along the northwestern boundary of the cyclone towards the Yucatan Shelf. The other group meanders northward as they encounter the early formation of another cyclone off the West Florida Shelf.

To illustrate the impact rings and eddies have on advection in the open Gulf, eastward advection patterns during a 30 day time frame are detailed in Figure 2. See Kirwan et al (2002). The “escape time” of particles in the western Gulf, that is those initially west of 90^{o}W, is taken to be when they first cross this longitude. Note the filamentary nature of the particles that escape. Based on the model height alone, it is impossible to determine which particles will cross the longitude. Material curves that emanate from five hyperbolic trajectories, labeled D-H in the figure, show this eastward advection is governed by inter-eddy channels which rapidly transport fluid. Similar channels advect fluid rapidly westward in the Gulf.

IMPACT/APPLICATIONS

An important impact on and application to both model assessment and data assimilation exists. Lagrangian data has not been used extensively to validate with model results due to limited comparison methods available. The material curve methods used here provide a new way to reconcile Lagrangian data with Eulerian current maps. Material boundaries reveal Lagrangian aspects of the flow, which may be reconciled with drifter paths or other tracer data.

Although this research is concentrated in the Gulf of Mexico, the methods are generic and thus applicable in any region in the world ocean.

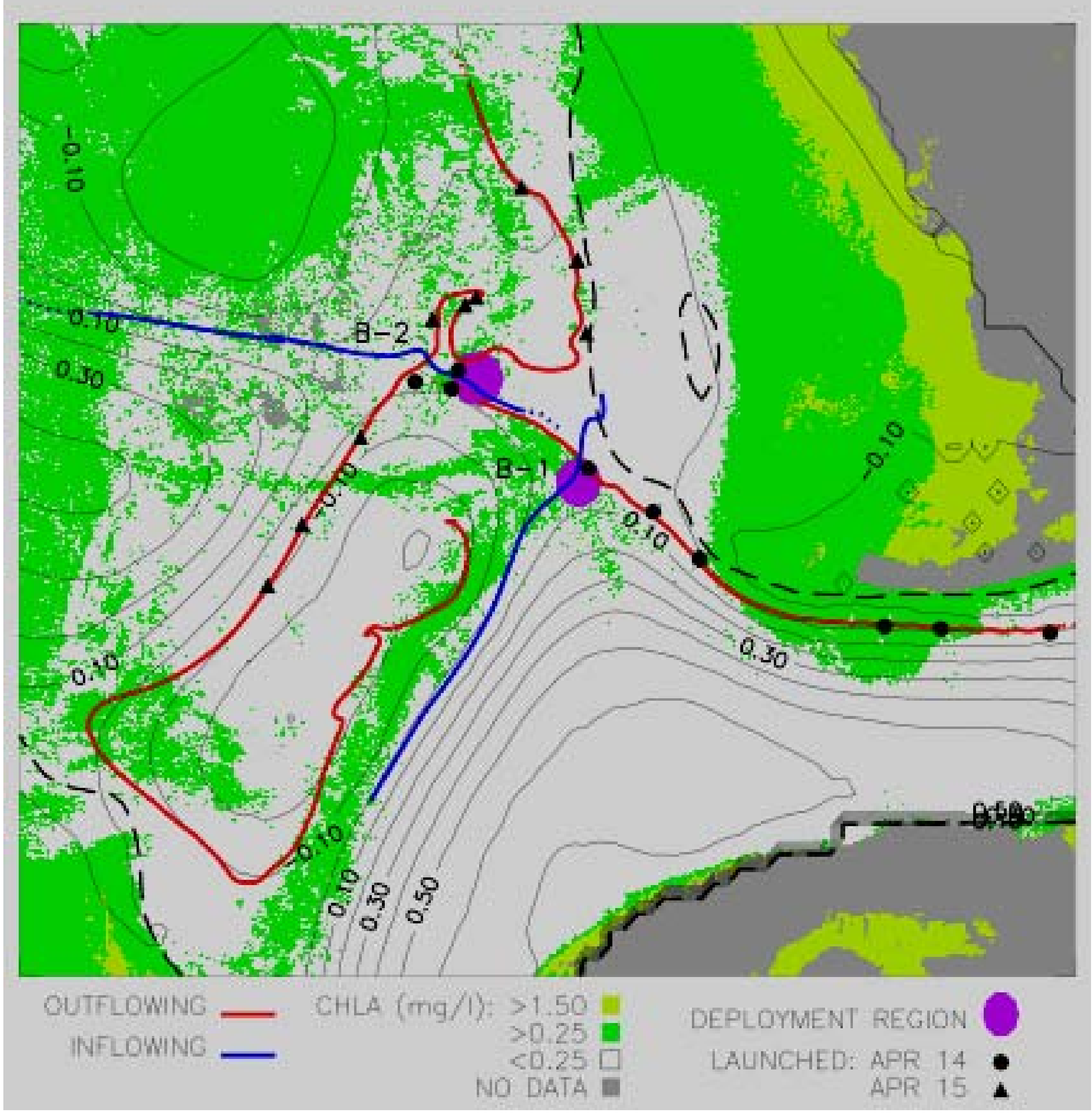

Figure 1: April 17, 1998. Expected behavior of drifter deployments surrounding two hyperbolic trajectories: B-1 located on the northern extent of the Loop Current and B-2 located northwest of B1. Six of the nine drifters launched on April 14 surrounding B-1 follow the northern boundary of the Loop Current past the southern tip of Florida.. The other three drifters follow the northern boundary of the adjacent cyclone towards B-2. Three of the nine drifters launched on April 15 surrounding B-2 follow the western boundary of the cyclone south towards Yucatan, while the other six follow a meandering path northward.

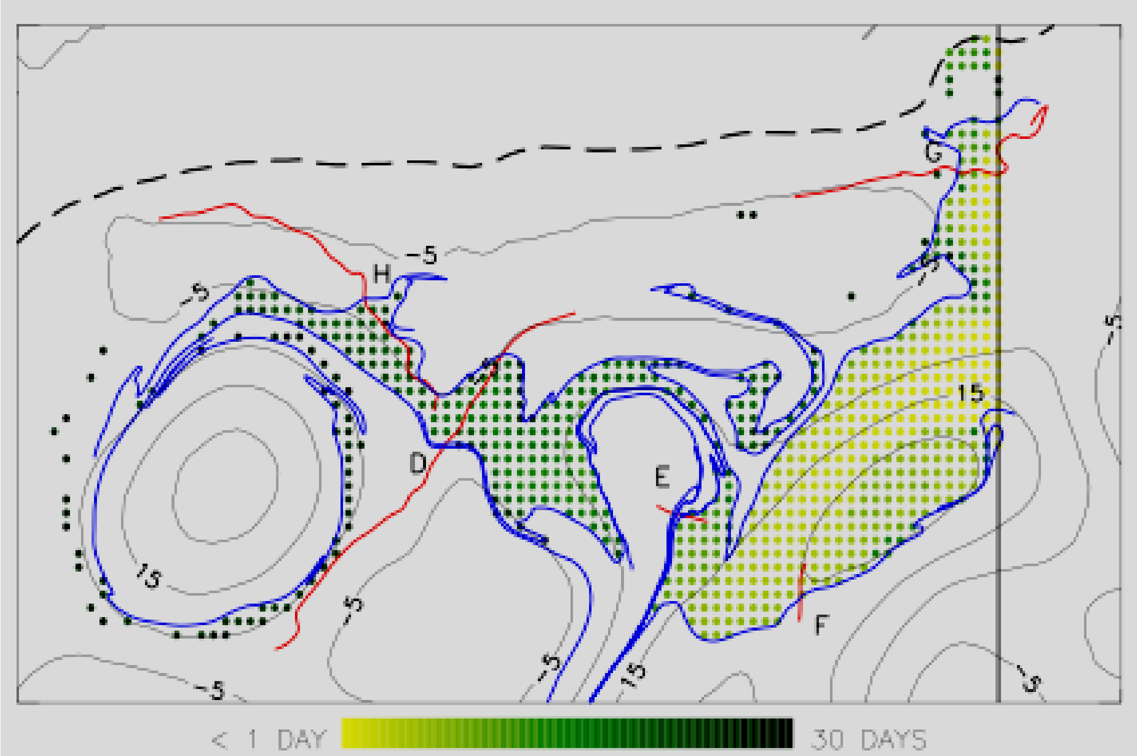

Figure 2. July 22, 1998. Eastward advection across a longitude is detailed by particles initialized west of 90^oW. Those that cross this longitude are colored based on how long they take to cross. Material curves that emanate from five hyperbolic trajectories are computed to detail how this eastward, inter-eddy advection may be delineated.

TRANSITIONS

The methodology in this study will be used to further 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 masters thesis by Elias Hunter titled, “Advective Transport on the Louisiana-Texas Shelf,” at The University of Delaware. This effort was an extension of the work done by LCDR William Schultz where 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 analyze HF radar data, provided by Jeff Paduan at the Naval Postgraduate School, in Monterey, CA through another ONR project, N00014-00-1-0067. The emphasis of that project is advective transport using Lagrangian methods.

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