

# **Integrating Feature-Oriented High-Resolution Synoptic Observations for MODAS**

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## **LONG-TERM GOALS**

Our long-term goal is to develop a generic real-time shallow water capability for the Modular Ocean Data Assimilation System (MODAS), which will provide high horizontal resolution (1-10km) synoptic observations for operational nowcasting and forecasting for the U.S. Navy. Concurrently, we will develop a set of generic and portable shallow water feature models for application to *shallow waters* (< 30 m) *anywhere in the world*.

## **OBJECTIVES**

Our overall objectives are twofold: (1) to implement and evaluate existing feature-oriented regional modeling system (FORMS) capabilities in the MODAS; and (2) to develop new FORMS for additional features of shallow water regimes.

## **APPROACH**

The FORMS for the Gulf of Maine and Georges Bank (GOMGB) region has been developed for real-time applications for medium-range (7-10 days) sub-mesoscale (<5km) forecasting (Gangopadhyay and Robinson, 2002; Gangopadhyay *et al.*, 2003). Previously, Hurlburt *et al.* (1990, 1996) and Fox *et al.* (1992) have used similar approaches for the Navy. This methodology is model-independent, and can be applied in lieu of or in addition to satellite or *in situ* observations. In coastal regions, the feature-oriented methodology requires developing a synoptic circulation template for the region of interest.

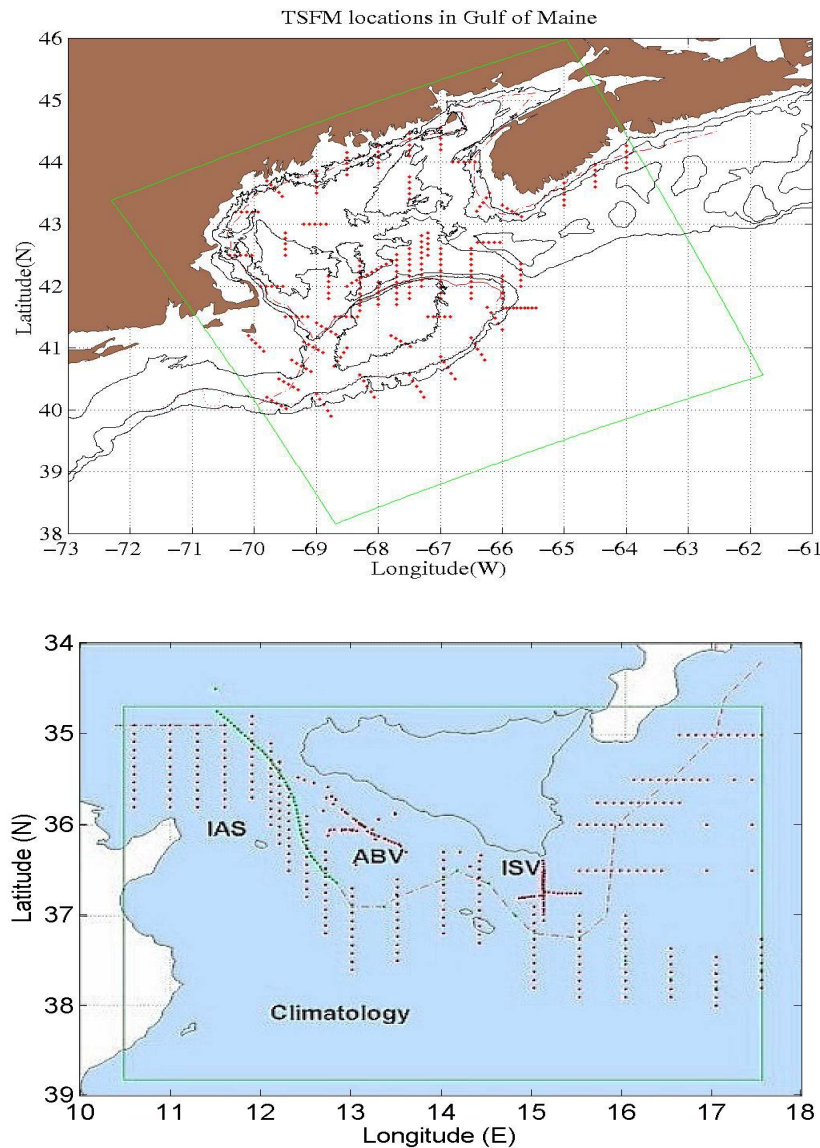
# Report Documentation Page

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This template is designed from a feature-based synthesis of the regional circulation pattern. From this “basis template,” a map of strategic sampling locations for placing feature model profiles is produced. These profiles provide “synthetic synoptic expressions” for fronts, eddies, gyres, and other circulation structures (e.g., jets, squirts, and filaments) and water masses at the initialization or updating phases.



**Figure 1. Synoptic feature-oriented circulation template or “basis template” for two regional oceans: Note that only a limited number of stations -- 270 for GOMGB (left), and 200 for the Strait of Sicily (right) -- are needed to describe the synoptic behavior of these regional oceans.**

A set of twin experiments will be carried out to evaluate the MODAS analysis and MODAS/NCOM (nowcast/forecast) systems with and without FORMS synthetics for the two regions shown in Figure 1. A number of specific tasks will be accomplished in this project. These are: (i) incorporate existing feature models for GOMGB and the Strait of Sicily into MODAS; (ii) develop feature oriented circulation templates for the California Coastal Current system, the Persian Gulf, the Gulf of Mexico and the Korean Straits (ASIA-EX); (iii) develop process-oriented shallow water (<30m depth) feature models for upwelling regions, density-driven plumes, jets, squirts and shelf eddies; (iv) use satellite

data (SST and color) to identify and characterize the shallow features; (v) use EOFs (for T-S) and velocity-projection (for u, v) to vertically extend the shallow features; and (vi) develop error fields for FORMS and integrate into MODAS for the Navy's operational systems.

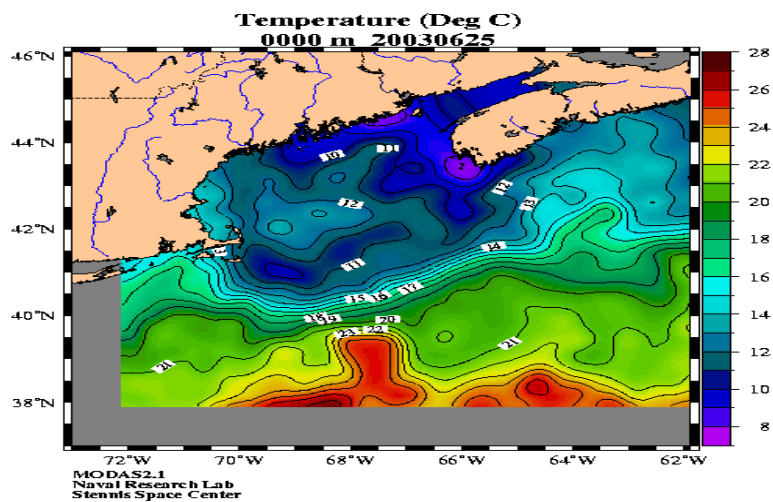
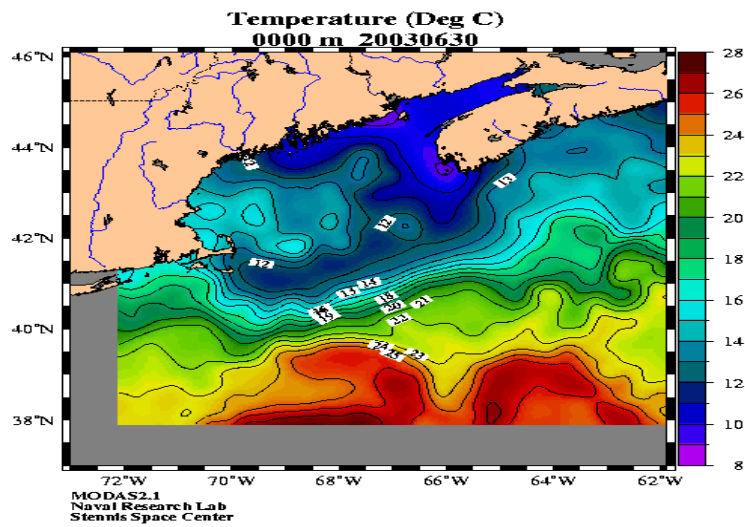
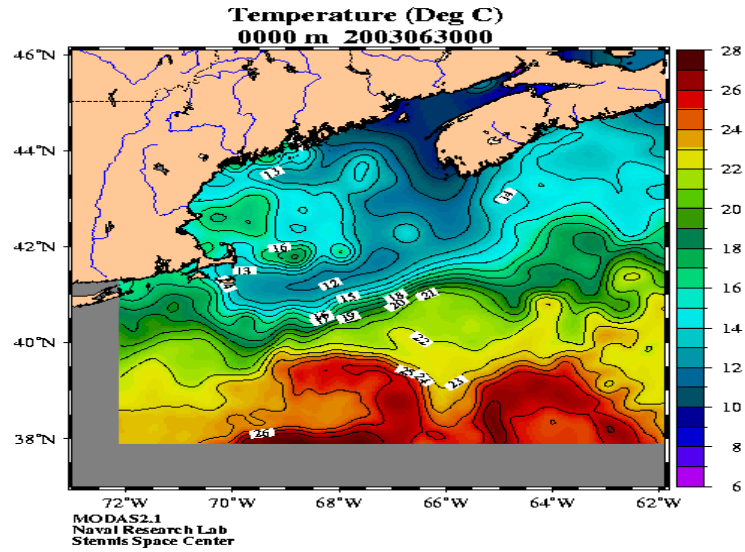
This is a collaborative project lead by the University of Massachusetts and closely coordinated with NRLSSC and NAVOCEANO. Gangopadhyay is leading the group at UMASSD. Dr. Hyun-Sook Kim, an expert in numerical modeling and data synthesis, joined as a Research Associate in September 2003. Dr. Chithra Shaji, another modeler from U Miami, will join in November 2003. Three graduate students are partially funded to develop feature identification and tracking from Satellite images. Incorporation of the existing feature models into MODAS is being carried out in a collaborative manner with NRL scientists, Fox and Dr. Clark Rowley. EOF-based work is being led by Warn-Varnas. Dr. Frank Bub is consulted in our activities for proper and efficient implementation for operational needs.

## **WORK COMPLETED**

This project is a new start late in FY03. The grant was awarded in February 2003. During March 17-20, 2003, Gangopadhyay visited NRLSSC for detailed discussions on how to achieve the goals and objectives that we set forward in the proposal. A document describing the work plan developed and the issues raised during various meetings and discussions was previously submitted to the ONR program office. Here we describe some of the actual tasks partially completed and technical accomplishments.

### *Implementing FORMS Synthetics in MODAS for GOMGB*

The NRLSSC group has implemented a regional setup for the twin experiments in the GOMGB region. The regional MODAS runs in a 5-km-resolution domain. Three simulations were carried out using the FORMS generic synthetics (locations and t-s profiles) for the GOMGB by Fox and Rowley. Preliminary results are shown in Figure 2: (i) a MODAS reanalysis (left), (ii) a reanalysis of MODAS + FORMS synthetics for June (middle), and (iii) a reanalysis and 10-day assimilated adjustment starting from the results of (ii) and using a shorter space-time decorrelation scale to preserve more of the details from the feature model (right). These results are being analyzed at the present time.

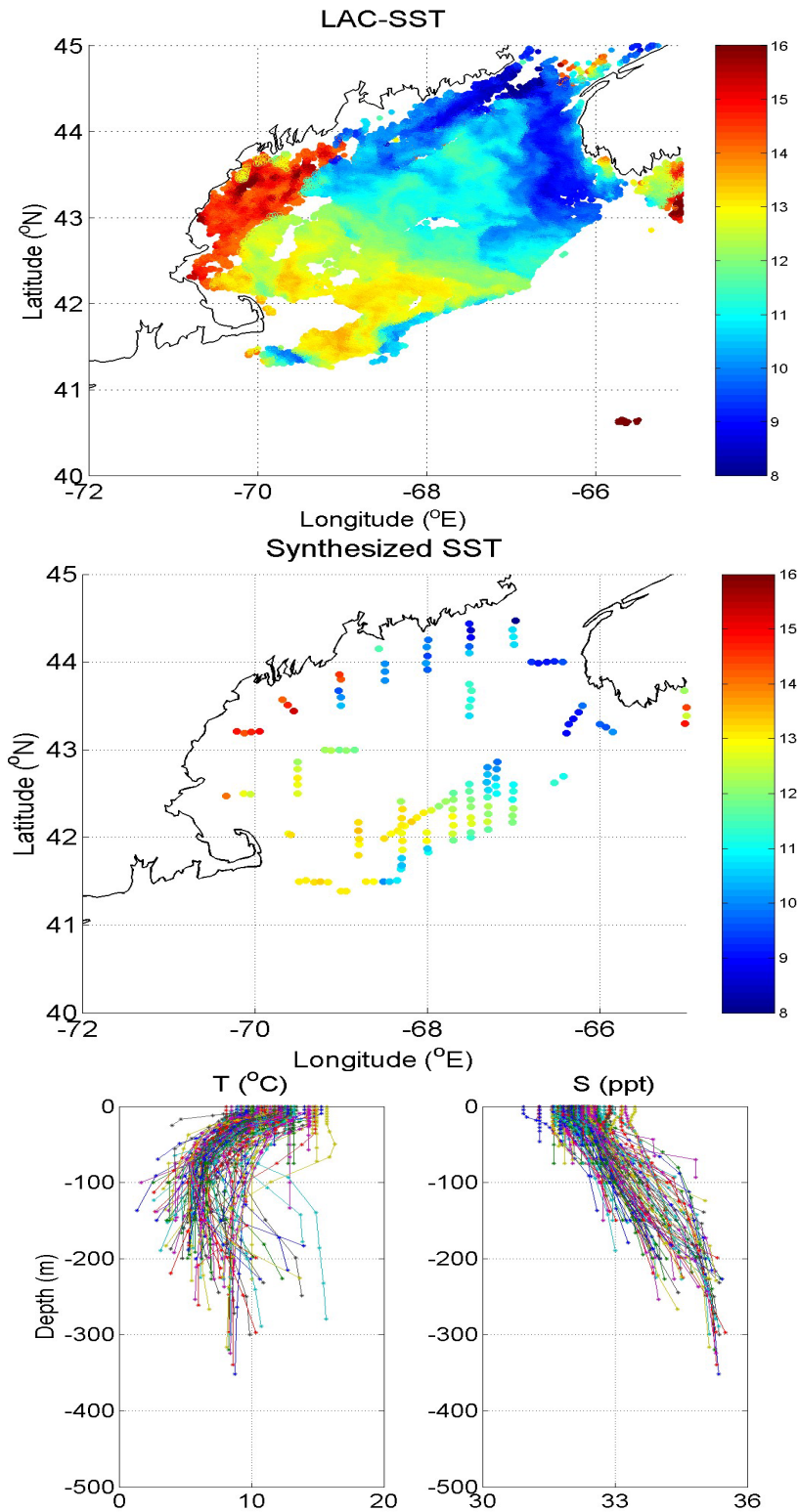


*Figure 2. Possibility of progressive improvement of meso and submesoscale features in GOMGB from left (Reanalysis) to middle (MODAS+FORMS reanalysis) and to right (reanalysis + assimilation).*

### *Generation of t-s Profiles Using FORMS from SST Images for MODAS*

A major technical accomplishment in this period is the development of a technique to generate temperature and salinity profiles using available SST and the vertical structure function  $\phi(z)$  from FORMS. This procedure depends on describing the temperature profile at a location as follows:  $T(z) = (T_0 - T_b) \phi(z) + T_b - (1)$ , where  $T_0$  and  $T_b$  are the surface and bottom temperatures respectively. Given the developed FORMS for a region, one can use the above equation to generate  $\phi(z)$  at any of the feature locations (red dots in Fig. 1).

For a region, sampling of the available SST at the FORMS-defined locations results in surface temperature at those locations. Using equation (1) with  $T_0$ =SST,  $T_b$  from Climatology, FORMS or model forecasts, and  $\phi(z)$  a new  $T(z)$  for that location is derived. This new  $T(z)$  is now calibrated for the available SST. The salinity profile can then be obtained by using the FORMS t-s relationship at this location. An example case for June 2003 is shown in Figure 3, which was selected because of its high-resolution data availability from the Local Area Coverage (LAC) MCSST fields.



**Figure 3. (a) LAC MCSST for 6-20-03; (b)  $T_0$  from SST at FORMS locations; (c)  $T(z)$  and  $S(z)$  synthetics using SST, FORMS and  $(\phi(z))$ .**

## *Shallow Water Feature Models -- California Current System FORMS*

We are researching various aspects of the synoptic variability of the prevalent circulation features in Monterey Bay and its adjacent areas including the CCS during the summer (July-August) season. These features include the mean flow and the southwestward meandering jet of the California Current, the poleward flows (California Undercurrent and inshore current), the coastal transition zone features, i.e., the coastal eddies, the coastal jets along the upwelling fronts, the anomalous pools, the large and small filaments (squirts), and the mushroom vortices. We have identified the typical synoptic width, location (distance from the coast), vertical extent, and core characteristics of these features and their dominant spatial and temporal scales of variability from past observational, theoretical and modeling studies. These are documented in a “Working paper” ([www.smast.umassd.edu/modeling/ccs.pdf](http://www.smast.umassd.edu/modeling/ccs.pdf)). The FORMS development for the Gulf of Mexico, ASIA\_EX and the Arabian Sea will begin shortly.

### *EOF Analyses in the Gulf of Maine and Monterey Bay*

EOF analysis was carried out for two regions: (i) Wilkinson Basin and (ii) Monterey Bay. The Wilkinson Basin analysis was completed during the first two months of this project, and a paper was submitted to the *Continental Shelf Research*. These analyses are the pre-cursors to our effort to connect the vertical structure of a feature to the EOFs of the constituent water masses of that specific feature on the basis of their spatial eigenfunctions (Fukumori and Wunsch, 1991).

Cluster analysis was applied to the Monterey Bay August 2000 data set prior to EOF analysis. Five distinct water masses were identified. The Bay Surface Water (BSW) and a warmer Bay Warm Water (BWW) were on the surface layers. Below the surface are the Monterey Bay Intermediate Water (BIW) and the Subarctic Upper Water (SUW) (Tomczak and Godfrey, 1994). At the bottom is the North Pacific Deep Water (NPDW). Five EOFs were calculated for each of these water masses. A manuscript is in preparation. We will also develop a water-mass-based feature model for ASIAEX.

### *Velocity Projection Work*

We modified a methodology for estimating subsurface velocity structure in an outflow plume in the Chesapeake Bay following Marmorino *et al.* (2003). A first-order dynamical feature model for a typical plume was developed using theoretical models and past synoptic observational data sets. Feature parameters include the location and extent of the frontal boundary, a simplified gravity current structure in the vertical with prescribed (or inferred) density stratification, and spatial gradient of salinity across the frontal head of the plume.

The velocity projection method by Shen and Evans (2001) obtains subsurface current structure within the Ekman layer depth from surface currents (HF radar) and wind observations. The ‘feature model’ density stratification in shallow water is incorporated now in the dynamical projection equations. The resulting subsurface projected currents are compared and calibrated with available ADCP profiles. This approach can be applied to other shallow water features like salt lenses and other anomalous entities. A paper co-authored by Gangopadhyay, Shen, Marmorino and Mied (from NRL-DC) is in preparation.

## RESULTS

In summary, the significant results for this project during the initial seven months are: (1) a new methodology to generate synthetic synoptic profiles for temperature and salinity utilizing high-resolution SST and FORMS vertical structure  $\phi(z)$  was developed; (2) a set of shallow water features have been identified and their variability documented for feature modeling for the CCS; (3) an EOF based water mass characterization of the Monterey Bay regional circulation (for summer 2000) has been completed for both upwelling and relaxed periods; and (4) a simple plume feature model was successful in providing the required background stratification to a velocity projection method to extend surface HF radar velocity information in the vertical.

## IMPACT/APPLICATIONS

The vertical extension procedure of LAC data will be useful for initialization and assimilation of SST in Monterey Bay and other regions. The velocity projection methodology will be applicable to CODAR, and will be tested for GOMGB and Monterey Bay regions.

## RELATED PROJECTS

This research is closely related to another project led by Gangopadhyay, entitled: "Implementing FORMS for the Monterey Bay forecasting system using HOPS and ROMS", N00014-03-1-0206. The shallow water feature models will be developed for the CCS and used in numerical models collaboratively between these two projects. Similarly, the EOF analysis of water masses will be used to develop regional climatology for Monterey Bay and the California Current System.

## PUBLICATIONS

"Wilkinson Basin Water Masses: A revisit with EOFs", A. Warn-Varnas, A. Gangopadhyay, J. Hawkins and A. Robinson. Submitted to *Continental Shelf Research*, 2003.

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