Implementing FORMS for the Monterey Bay Forecasting System Using HOPS and ROMS

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LONG-TERM GOALS

Our long-term goal is to implement the feature-oriented regional modeling methodology for the Monterey Bay (MB) forecasting system in retrospective and real-time operations using (i) the Regional Ocean Modeling System (ROMS) and (ii) the Harvard Ocean prediction System (HOPS).

OBJECTIVES

Three specific objectives are pursued to achieve our long-term goal: (i) to develop a synoptic high-resolution regional climatology for Monterey Bay and the California Current System (CCS), (ii) to implement the feature-oriented regional modeling system (FORMS) capabilities in the West Coast ROMS and HOPS modeling efforts for synoptic nowcast, forecast and 3D-VARS and ESSE-based assimilation in the Monterey Bay region, and (iii) to apply this methodology in real time within the nested ROMS and HOPS modeling efforts.

APPROACH

The western coast of the U.S. includes both an offshore region and a very dynamic coastal region. The offshore region is primarily dominated by the large-scale California Current, the California Undercurrent and parts of subtropical and sub-polar gyre circulations in the eastern Pacific. The coastal region includes features such as upwelling fronts, cold pools inshore of these fronts, filaments, squirts, mushroom-head vortices, mesoscale and sub-mesoscale eddies, and meanders.

In the FORMS approach (Gangopadhyay and Robinson, 2002; Gangopadhyay *et al*., 2003), such structures and their parameterized forms can be implemented to characterize the relevant circulation entities. Such implementation requires careful and detailed scientific analyses to identify the spatial and temporal scales and variability that define and distinguish these features from one another while preserving their individual characteristics. After the major features are identified and their representations chosen, the latter are used in the initialization of a basic dynamical model (e.g., HOPS or ROMS). Dynamical adjustment accomplishes two important tasks: i) a consistent dynamical interaction of the features, and, ii) the generation of smaller scales, such as squirts and sub-mesoscale eddies. We will carry out a series of numerical experiments to implement the feature models in the CCS within the nowcast-forecast-assimilation framework of both ROMS and HOPS.

Figure 1 shows the different components of our overall approach in a conceptual flow-chart. Note that this approach is sufficiently generic for application to other numerical models.

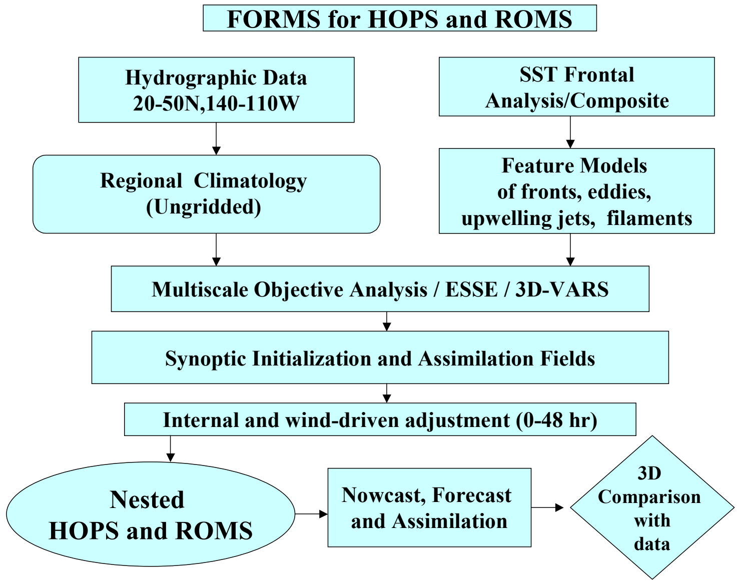

Figure 1. Our approach to FORMS implementation for HOPS and ROMS.

This is a collaborative project led by the University of Massachusetts and closely coordinated with Harvard (HOPS) and JPL (ROMS). Gangopadhyay is leading the group at UMASSD. Dr. Hyun-Sook Kim, an expert in numerical modeling and data synthesis joined the group as a Research Associate in September 2003 and is helping to develop the regional climatology.

WORK COMPLETED

This project was a late start (enhancement to an earlier smaller project) in FY03 and is gathering momentum as described below.

(1) Regional Climatology Development

Due to the effect of El Niño in the eastern Pacific, we propose to develop a Warm Climatology and a Cold Climatology. These could relate to the opposing phases of the Pacific Decadal Oscillation (http://tao.atmos.washington.edu/pdo), as well as to the El Niño vs. La Niña years. However, sparse data availability in the offshore regions has restricted such a development. In lieu of such desirable climatology, the GDEM climatology was used for synoptic initialization schemes during August 2003.

Two different periods have been selected for the PDO phases: 1978-1992 for the warm and 1962-1974 for the cold. Additionally, three different sets of years during El Niño, La Niña and Normal periods have been identified. The available data (temperature and salinity) during the summer months (June, July and August) for these three periods at the surface and at 5 m are shown on the website: http://oceans.deas.harvard.edu/haley/AOSN2/Climo/.

We have recently acquired other data sets from Scripps, UCSC, UCSB and NPS. Some of these high-resolution-coverage datasets are shown in Fig. 2(a) along with the CALCOFI low-resolution data set for the month of August. We are developing a grid with sizes increasing from 5-km near shore to 25-km offshore. The climatology analysis was performed using a density-layer approach developed and calibrated for the Gulf of Maine by our group (Brown *et al.*, 2003). In the future, this density-layer approach will be useful to implement an EOF-based, feature-oriented synoptic climatology development. A recent water mass EOF analysis using the MUSE 2000 data, carried out by Warn-Varnas *et al.* (2003), will be augmented by the AOSN-II 2003 experimental data sets.

Figure 2(b) shows the preliminary ungridded temperature climatology in the Monterey Bay region based from data from NPS and NODC only. A statistical procedure has been developed to eliminate adjacent observations, which show large differences due to the fact that they are from different years, which were affected by either El Niño or La Niña. These large differences in close proximity often result in spurious eddies and artificial fronts in a numerical initialization and assimilation.

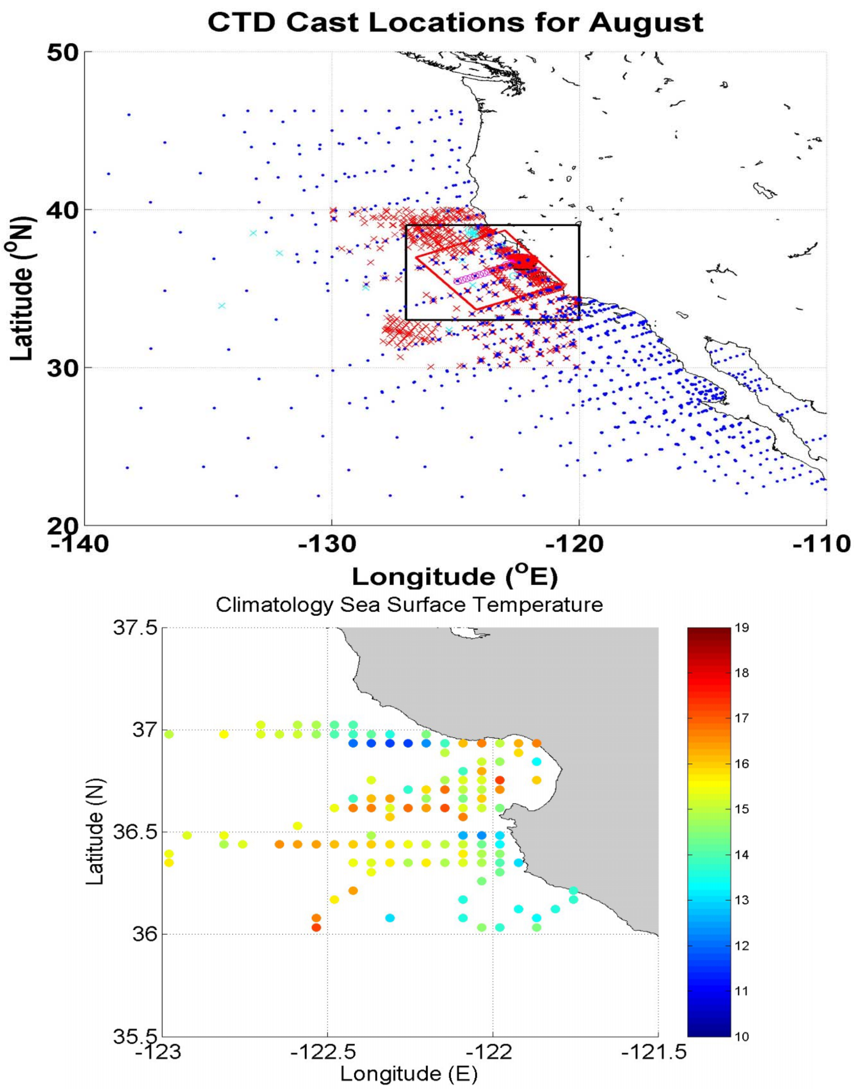

Figure 2. (a) Domain and a subset of available data in the eastern Pacific. (b) Prototype ungridded climatology for Monterey Bay for August for a limited data set.

(2) Numerical Simulations with HOPS -- Monterey Bay Circulation Template Development

During the AOSN-II experiment in August 2003, Gangopadhyay participated in analyzing the HOPS simulations in a research mode. It was clear from the beginning that this region is highly variable and inhibited by a number of different water masses due to various offshore-onshore interactions. On the basis of our analysis prior to and during the AOSN-II experiment, we are now in a position to develop a circulation template for the Monterey Bay region. In summertime, the Bay circulation shows two distinct hydrographic states: upwelling (1-3 weeks) and relaxed (3-10 days). These two periods are related to the prevailing wind patterns and scales forcing such states. During the upwelling periods, the typical circulation in and around Monterey Bay consists of an upwelling front originating from Pt. Ano Nuevo, a cyclonic circulation inshore of the front in the Bay, an anticyclonic eddy-like circulation on the offshore of the upwelling front and another upwelling region off Pt. Sur. As the wind relaxes, the upwelling weakens, and the offshore eddy-like circulation (presumably part of the California Current meandering flow system) flows into the Bay and interacts with the flow over the shelf. These features are listed in Table 1.

A "synoptic circulation template" will be developed for initialization and assimilation purposes based on above conceptual circulation features. The same "basis template" will provide three-dimensional temperature, salinity and velocity information to both HOPS and ROMS modeling systems.

The upwelling frontal region can be "feature modeled" as a "bifurcating upwelling frontal system" based on the Ekman flow dynamics near a cape (Rosenfeld *et al*. 1994; Section 5.5, Fig. 16 and supporting equations). The connection between these wind-derived velocity fields and the underlying temperature-salinity structure will be developed by extending the Ramp *et al*. (1997) study, high-resolution synoptic data from Rosenfeld *et al*. 1995, and further analysis of the 2003 AOSN-II exercise.

Table 1. Circulation features in the Monterey Bay region during upwelling and relaxed periods

	Upwelling State	**Relaxed State**	**References**
Temporal Scale	1-3 weeks	3-10 days, sometimes > 10 days	AOSN-II Expt, Aug 2003
Features	Bifurcating upwelling frontal system from Pt. Ano Nuevo	Disorganized flow; wind drives the upper water onshore; northward flow in northern half; southward flow in southern half	Rosenfeld *et al.* (1994); Ramp et al. (1997); Rosenfeld et al (1995)
	Anticyclone eddy on the offshore side of the offshore upwelling filament	Anticyclone eddy moves onshore	Tracy (1990) and others previously noted in Working paper on the web
	Cyclonic circulation in the bay	Cyclone reduces its extent (Does it intensify?)	Tracy (1990) and others noted in working paper
	Bifurcating upwelling frontal system from Pt. Sur	Smaller cyclone near Pt. Sur, northward flow near surface – coastal jet	Traganza *et al.* (1981); Tisch and Ramp (1997) and others

(3) Numerical Simulations with ROMS

The ROMS modeling system was ported from JPL and was installed during summer of 2003 at UMass Dartmouth. A 30-day simulation was then carried out using a GDEM climatological initialization. The domain is compared to the L3 domain of the JPL group (see ourocean.jpl.nasa.gov for details) during the ongoing AOSN-II exercise. The temperature field evolution showed realistic features in the CCS. However, the mesoscale and submesoscale features were absent in this initialization, which will be the focus of our work in the coming year. Software has been developed to convert the regularly gridded feature-based initialization OA to the required input fields for ROMS on the model grid.

RESULTS

Significant progress has been made in three aspects. The elements of the circulation template for both the upwelling and relaxed phases of the Monterey Bay regional circulation have been identified. A major difficulty in this region has been quantifying the variability of water masses and their inter-relationship with the CCS. The effort to develop the regional climatology clearly pointed out the lack of data in many regions of the coastal as well as offshore regions. We have started a major effort in gathering data sets for the whole region: 20-50N, 140-110W. This regional climatology will be made available to the community at large. The feature models for the upwelling fronts and coastal eddies in the MBay region will be implemented in the background of this regional climatology for the HOPS and ROMS modeling groups for usage in the 2005 AOSN-II real-time experiment.

IMPACT/APPLICATIONS

Regional climatology on a variable grid will be made available to the community at large. Climatology on the basis of water masses would be useful to incorporate EOFs.

RELATED PROJECTS

This research is part of the larger AOSN-II effort by Bellingham and Chandler (Autonomous Ocean Sampling Network II (AOSN II): System Engineering and Project Coordination - N00014-02-1-0856). Closely related research on ROMS is that by Chao (Development of a Monterey Bay Forecasting System Using the Regional Ocean Modeling System (ROMS) - N00014-03-1-0208), and on HOPS is that by Robinson (Development of a Regional Coastal and Open Ocean Forecast System: Harvard Ocean Prediction System (HOPS) - N00014-97-1-0239). This project is also very closely related to another project to Gangopadhyay, which is entitled: "Integrating Feature-Oriented High-Resolution Synoptic Observations for MODAS" - N00014-03-1-0411. The work on regional climatology development is a collaborative effort with the UCSC group (McManus and Chavez - Autonomous Ocean Sampling Network II: Assessing the Large Scale Hydrography of the Central California Coast - N00014-03-1-0267), and with the NPS group (Rosenfeld and Paduan) with Shulman (NRL), McGillicuddy (WHOI) and Haddock (MBARI) (Use of a Circulation Model to Enhance Predictability of Bioluminescence in the Coastal Ocean - N00014-03-WR-20009).

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