

Boundary Conditions, Data Assimilation, and Predictability in Coastal Ocean Models

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LONG-TERM GOALS

The long-term goals of this research are to improve our ability to understand and predict environmental conditions in the coastal ocean.

OBJECTIVES

The specific objectives of this research are to determine the impact on coastal ocean circulation models of open ocean boundary conditions from Global Ocean Data Assimilation Experiment (GODAE) Pacific Ocean models, and to address closely related issues of uncertainty and predictability in coastal ocean models.

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APPROACH

This research addresses the direct impact on coastal models of boundary conditions from GODAE models. The domain of the nested coastal model is the 'coastal transition zone' (CTZ), which includes the continental shelf and slope, and the adjacent ocean interior. The CTZ is the natural oceanographic regime of interest for coastal modeling applications off Oregon and northern California. It extends offshore about 200 km in this region, and is characterized by energetic wind- and buoyancy-driven flow over the shelf, accompanied by complex, lower-frequency eddy, jet and filament dominated flow over the slope and in the ocean interior, which is unlikely to be properly resolved by basin scale models. The impact on the CTZ-domain model simulations of assimilating satellite observations, and of using scatterometer wind stress fields, will also be addressed. Validation of the simulated coastal ocean circulation is provided by existing elements of the Oregon coastal ocean observing system. The impact of the boundary conditions is being assessed quantitatively. The closely related issues of uncertainty and predictability in coastal ocean models are being addressed using a variety of empirical and theoretical methods to study disturbance growth mechanisms and to develop uncertainty budgets for these models.

In addition to PIs Samelson, Allen, Egbert, Kindle, and Snyder, other senior personnel are A. Kurapov and R. Miller, both at College of Oceanic and Atmospheric Sciences, Oregon State University. Dr. Scott Springer has been hired as a full-time research associate to pursue the physical circulation modeling, data assimilation and boundary condition assessment studies. Postdoctoral investigator Dr. Sangil Kim joined the project in July 2006 to work on the predictability and uncertainty studies.

WORK COMPLETED

The work plan primarily involves the implementation, evaluation, and analysis of a nested CTZ-domain model based on the ROMS (Regional Ocean Modeling System) primitive equation modeling code. Since the GODAE Pacific HYCOM model at present is not yet functioning with full data assimilation capability, it was decided, in consultation with NRL partner John Kindle, to proceed with nesting the CTZ-domain ROMS model in the NRL regional NCOM-CCS (Navy Coastal Ocean Model-California Current System) model. The latter regional model is nested in the Navy's Operational Global NCOM model, which is a component of the Global Ocean GODAE system. Both Global NCOM and NCOM-CCS include assimilation of satellite altimeter and sea-surface temperature measurements. NCOM-CCS has higher horizontal grid resolution than Global NCOM (9 km vs. 12 km) and, in addition, is forced by atmospheric fluxes from a high-resolution COAMPS (Coupled Ocean Atmospheric Mesoscale Prediction System) reanalysis product, which includes the orographically intensified wind stress in the Cape Blanco and Cape Mendocino regions. NRL partner John Kindle has provided the OSU investigators with NCOM-CCS model output for years 2000-2003, along with COAMPS forcing fields. NRL has work underway on implementing and evaluating a higher resolution (4 km) version of NCOM-CCS, the results of which from a preliminary run for the Summer of 2006 were provided for initial evaluation. Output from that model run for the 2000-2003 period, expected to be available in 1st quarter FY08, will be utilized for nesting a yet higher resolution CTZ-domain ROMS model. Results from the global NCOM have also been provided in preparation for future experiments that examine the sensitivity of the coastal ROMS model to the resolution of the model providing the boundary values. The NRL component is also examining the sensitivity of the regional NCOM-CCS model to inputs from the operational Global NCOM and the real-time Global HYCOM simulations.

In earlier work conducted under this grant, model results from NCOM-CCS (9 km) for year 2002, together with the associated COAMPS wind stress forcing fields, were compared with available satellite, HF radar, and in-situ measurements. In general, reasonable correspondence, for an outer domain regional model, were found. For example, the monthly-mean surface currents from long-range HF radar measurements showed generally southward surface currents in April and northward currents in December, and very similar qualitative behavior was evident in the NCOM-CCS model results.

During the past year, the nested CTZ-domain ROMS model, forced by the COAMPS wind stress, has been compared with in-situ measurements from the COAST (Coastal Ocean Advances in Shelf Transport) 2001 and 2003 and GLOBEC/NEP (Global Ocean Ecosystem Dynamics/Northeast Pacific) 2000 and 2002 field experiments.

For the uncertainty and predictability studies, two sets of ensembles of ROMS simulations of wind-forced coastal ocean circulation in a periodic alongshore-channel version of the CTZ domain have been constructed and analyzed, one forced by a time-periodic wind stress and one forced by a wind stress with time-dependence from a record of moored-buoy observations of wind stress over the central Oregon shelf. A predictability analysis based on these simulations has been nearly completed (Kim et al., 2007).

RESULTS

A non-assimilating 3-km CTZ-domain ROMS model has been nested in NCOM-CCS (9 km) and successfully run for seasonal simulations during 2001 (Springer et al., 2007). Several different sets of open boundary conditions have been tested. The set chosen for continuing analysis consists of a Flather condition for sea-surface height, a Chapman condition for barotropic velocity, and a radiation plus nudging condition (Gan and Allen, 2005) for baroclinic velocities and active tracers. The nudging timescale was set to one day on inward radiation, and the oblique radiation condition of Marchesiello et al. (2001) was used.

The nested simulations have been compared with observations during this period, with encouraging results. Surface horizontal velocity vectors from the nested CTZ-domain ROMS model compare well with coastal HF radar surface currents, with regard to both the spatial structure of the mean fields and the temporal structure of the fluctuating fields (Figure 1). An exception is the relatively small temporal correlations of model and radar surface currents are found at the southern, downstream edge of Heceta Bank, in a region of complex interaction between the wind-driven flow and the shelf topography.

Temporal correlations of depth-integrated model and observed principal-axis currents at moorings over the central Oregon shelf are similarly large, with values of 0.79, 0.85, and 0.84 along a line of three moorings across the shelf at 45 N, 0.78 at a mid-shelf mooring near 44.6 N, and 0.71 and 0.67 at the inshore and shelf-break moorings near 44.2 N (see Figure 1 for mooring locations). An exception is the 0.26 correlation at the mid-shelf mooring near 44.2 N, which is located near the center of the region of low correlation between the model and HF radar surface currents.

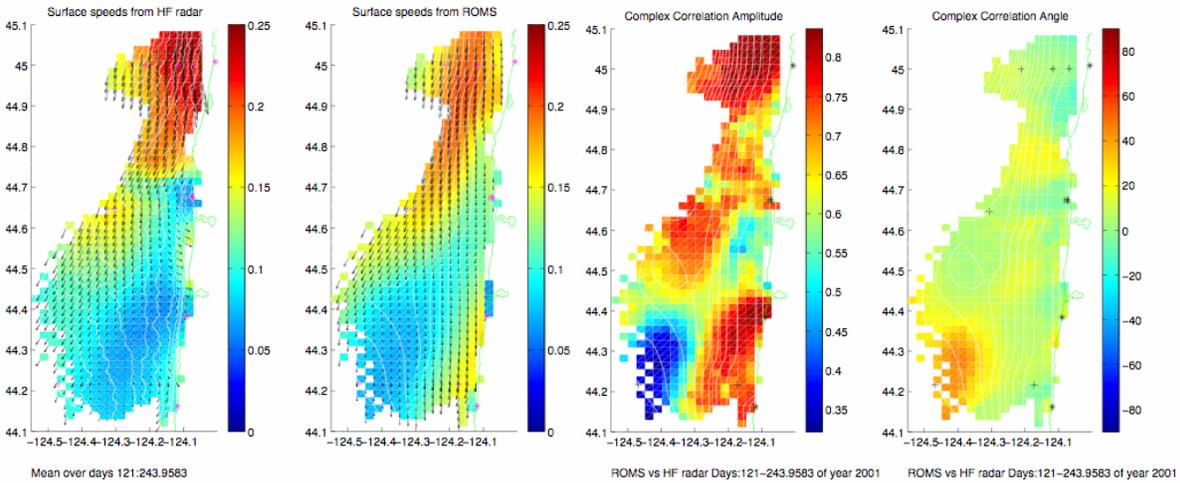


Figure 1: Comparisons of surface horizontal velocity off the central Oregon coast from HF radar observations and a CTZ ROMS simulation during days 121-243 of year 2001. Mean velocity ($m s^{-1}$) from HF radar (left panel) and from CTZ ROMS (second from left), and complex correlation amplitude (second from right) and angle (right) between HF radar and CTZ ROMS surface currents (for complex velocity variable $V = u + iv$) are shown. The locations of COAST current-meter moorings during 2001 are also indicated (+); the southern shelf-break mooring near 44.2 N was deployed farther offshore, outside of the region shown.

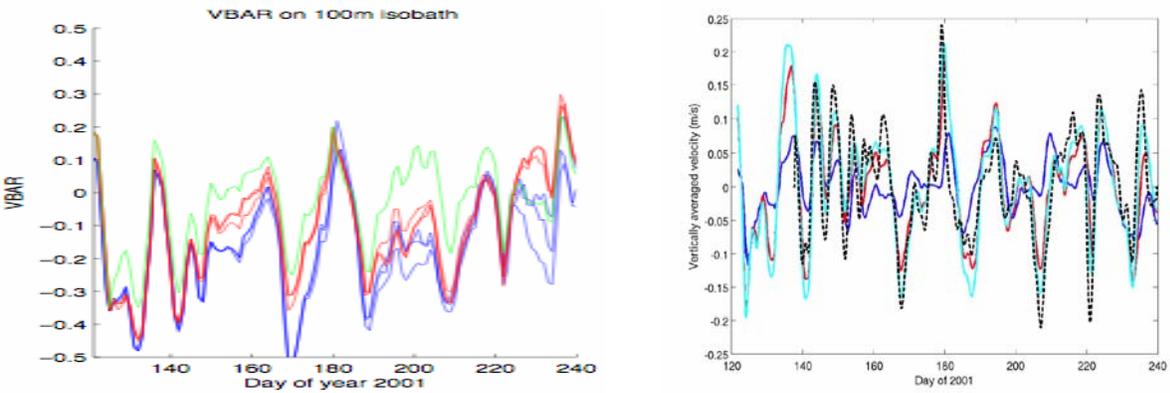


Figure 2: Time series of vertically averaged principal-axis velocities ($m s^{-1}$) near 45 N. Left panel: CTZ ROMS solutions with boundary conditions from NCOM-CCS with (red lines) and without (blue) assimilation and from climatological density fields (green), showing the sensitivity of the CTZ ROMS model to open boundary conditions. Right panel: Depth-integrated principal-axis velocity at the northern shelf-break mooring from observations (black dashed line) and from a coastal trapped wave (CTW) model. The CTW responses to the southern boundary condition from NCOM-CCS (dark blue) plus forcing south of 42.75 N (red) and south of 45 N (light blue) show the influence of the boundary condition and of winds in the Cape Blanco region on central Oregon shelf currents. The CTZ ROMS response to the southern boundary condition, diagnosed from the difference between simulations with NCOM-CCS and climatological boundary conditions, is similar to the CTW response.

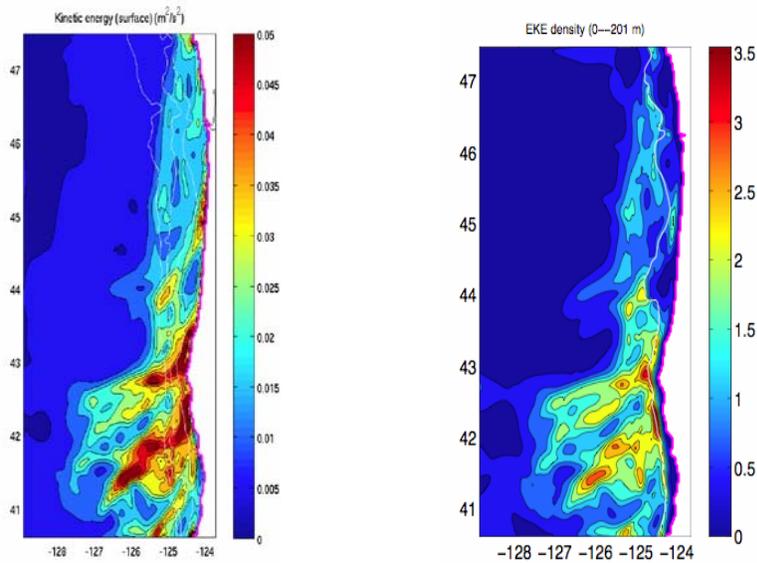


Figure 3: Surface (left, $m^2 s^{-2}$) and vertically (0-200 m) integrated (right, $m^3 s^{-2}$) eddy kinetic energy from the CTZ ROMS simulations, showing eddy formation and jet separation in the Cape Blanco region, south of 43 N.

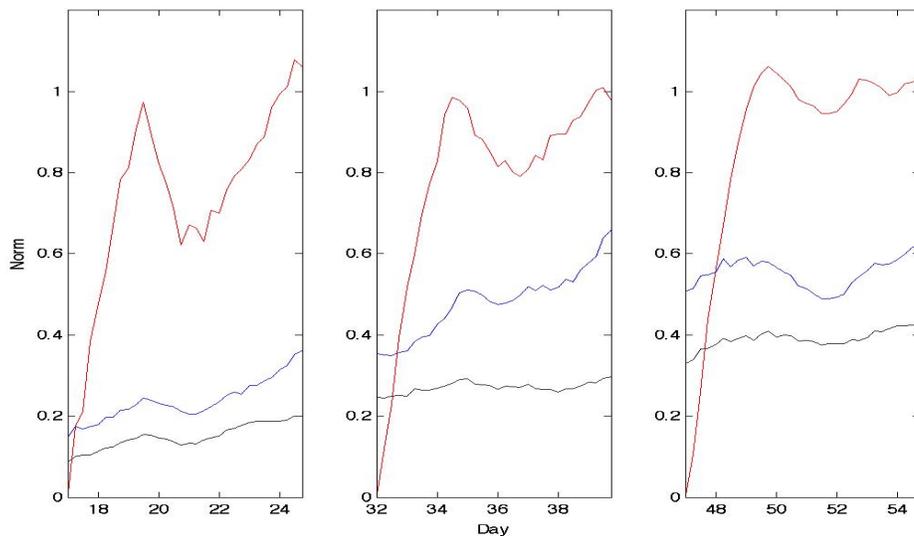


Figure 4: Norms of the difference of forecast and true solutions for persistence (red line), control (blue), and ensemble-mean (black) forecasts vs time (days) in predictability experiments using a 30-member ensemble of numerical simulations for wind-forced flow over the central Oregon shelf. The norm measures the average of scaled variances of the error (difference of forecast and true solutions) of sea surface temperature, salinity, height, and currents, relative to the time- and ensemble-averaged variances of the deviations from time- and ensemble-means of the corresponding variables.

Comparisons of simulations with boundary conditions taken from NCOM and from climatology have demonstrated the importance of the nesting approach for the representation of disturbances that propagate into the domain at the southern boundary as coastal trapped waves (Figure 2). Extension of this analysis has demonstrated that the dominant portion of the variance of alongshelf velocity over the central Oregon shelf is forced by winds in the Cape Blanco region, between 40 N and 42.75 N. The NRL component has also determined that for the period 2004-2006, the only period for which both real-time global HYCOM and NCOM results are available, the NCOM-CCS simulations were slightly more accurate along the Oregon-Washington coast when forced by global NCOM. Recent, independent work has shown that wind stress forcing in the Cape Blanco region is 3-5 times larger than that over the central Oregon shelf (Perlin et al., 2004). In this strongly forced Cape Blanco region, where coastal jet separation has frequently been observed, the CTZ ROMS simulations produce representative eddy formation and jet separation events (Figure 3).

Model-based predictability experiments have been conducted using ensembles of limited-domain numerical simulations of wind-forced flow over topography representative of the central Oregon shelf (Kim et al., 2007). In these experiments, in which one ensemble member is designated as the true solution, the error variance in persistence forecasts reaches climatological values after only 1-2 days, whereas the growth of ensemble variance and dynamical forecasts is slow (Figure 4). This suggests that significant components of the shelf circulation should be predictable using dynamical models on the 3-7 day predictability timescale of the atmospheric forcing. The limited ensemble variance growth in these simulations should be favorable to convergence of sequential-update or other data assimilation schemes for shelf flows.

IMPACT AND APPLICATIONS

National Security

The primary potential future impact of this project on National Security and Homeland Defense is improved understanding of and predictive capability for coastal ocean environmental conditions to assist security and defense operations in these regions.

Economic Development

The potential future impact of this project on Economic Development includes the stimulation of new business opportunities in coastal environmental prediction, based on improved understanding and predictive capability.

Quality of Life

The potential future impact of this project on Quality of Life includes better management of the coastal zone for public and ecosystem health, and resource extraction and sustainability, based on improved understanding of and predictive capability for coastal ocean environmental conditions.

Science Education and Communication

The potential future impact on Science Education and Communication includes better education of future research scientists, policy makers, and the general public, based on improved understanding of the coastal ocean.

RELATED PROJECTS

The model results obtained in the project are being compared with in-situ measurements from the National Science Foundation Coastal Ocean Processes/Coastal Ocean Advances in Shelf Transport (CoOP/COAST; <http://damp.coas.oregonstate.edu/coast/>) and Global Ocean Ecosystem Dynamics/Northeast Pacific (GLOBEC/NEP; <http://globec.coas.oregonstate.edu/>) field experiments. The research in this NOPP project is being closely coordinated with work in the OSU component of the GLOBEC/NEP project 'US-GLOBEC/NEP Phase IIIa – CCS: Effects of Meso- and Basin-Scale Variability on Zooplankton Populations in the CCS Using Data-Assimilative, Physical/Ecosystem Models' and in the OSU ONR project 'Data Assimilation in Shelf Circulation Models.'

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