# Final Technical Report
## Validation and Research Utilization of the NRL Regional Model for the U.S. West Coast

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## LONG-TERM GOALS

Our long-term goal is to understand the spatially and temporally varying circulation in the California Current System. One aspect of the circulation to be investigated is a quantitative description of the spatial and temporal variability of currents and water properties, including the seasonally varying fields and their higher order statistics.

## OBJECTIVES

In this project, we are examining output from the regional numerical circulation model in use by the U.S. Navy at NRL, as applied to the circulation of the California Current. We are also using those model fields to provide boundary conditions for nested models.

Our specific objectives are:
(1) To determine how well the regional nested NRL model reproduces the features and statistical fields as observed by satellite data and field surveys (the seasonal development of 2-D spatial structure of surface velocity and eddy statistics, the seasonal development of the 3-D circulation, Lagrangian eddy statistics, etc.).
(2) To use the model, in combination with the satellite and field data, to understand the processes that control transports in the large-scale eastern boundary current and the more detailed circulation over the shelf and slope; and

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(3) To develop the methodology for nesting high-resolution models of circulation over the west coast continental shelf and slope within the Navy regional model, to test the nested models by comparison with observations, and to use the nested models to study the dynamics of wintertime shelf circulation processes on the Northern California coast.

## APPROACH

Navy modelers at NRL are developing and using a regional, coastal ocean circulation model that can be implemented and relocated to any part of the global ocean, nested within the Navy's global ocean circulation model. They are presently testing the regional model in the California Current System (CCS) along the U.S. west coast from 30°N—50°N, using wind forcing from the U.S. Navy atmospheric model from July 1993 through 1997. This model (and its successors) will be used over the next five years in the CCS region under an internal NRL ARI with John Kindle as PI, including ecosystem and optical submodels.

Our general approach is to evaluate the realism of the NRL regional model by comparing statistical and dynamic analyses of the model output fields to identical analyses of satellite and in situ fields from the same regions and periods.

To investigate very high-resolution nested models, we conduct modeling studies of coastal circulation off Northern California in the vicinity of the Eel River (40.75°N - the site of the ONR-sponsored STRATAFORM observational program). We use a series of nested hydrostatic, primitive equation models in order to simulate coastal flow on a high-resolution grid of a limited area. For the nested simulations, the outer model is the NRL regional model of the NE Pacific Ocean with approximately 9 km resolution. Nests of approximately 3 km and 1 km grid spacing are used, with high resolution bathymetry and coastline and realistic river run-off. We simulate the shelf and slope flow surrounding Cape Mendocino during the winter of 1996-1997, during which period intense wind and buoyancy forcing characterized the Cape Mendocino area. The degree of realism of the different model simulations is assessed by comparison with measurements from the STRATAFORM program.

## WORK COMPLETED IN THIS PROJECT

Statistical analyses of the altimeter and SST data are in press [Strub and James, 2000]. Several evaluations of the in situ data have also been completed [Shearman et al. 1999, 2000a, 2000b]. The POM/ PWC model has been run from June 1993 though the end of 1997. We have calculated mean and eddy kinetic fields from model velocities and sea surface heights. These fields and their seasonal development have been compared to satellite altimeter data. To compare the trajectories of drifters in the region we seeded the model with clusters of simulated surface drifters. Drifter trajectories, and velocity and vorticity along the trajectories, have been analyzed and compared to real drifter statistics.

Two one-way nested grid models have been configured and simulated within the NRL model. The first nested grid extends approximately 200 km offshore and 475 km alongshore and has about 3 km resolution. This nested model was run for over 100 days during winter 1996-1997. The second nested grid is located within the domain of the first nested grid and extends about 125 km offshore and 275 km alongshore and has about 1 km resolution. This second nested grid model was simulated for 30 days - focused on the Eel River 80 year flood event that occurred in early January 1997. Both the time evolu-
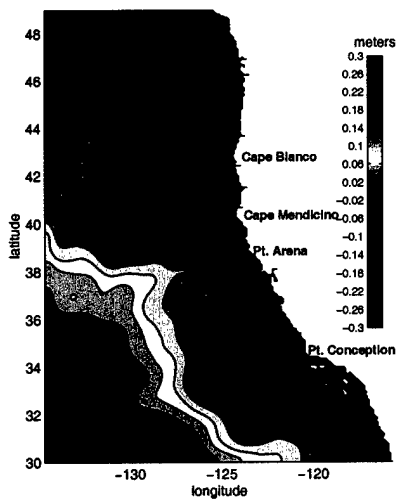
**1994-1997**



Figure 1. POM/PWC mean
SSH (1994-1997). CI=2cm.
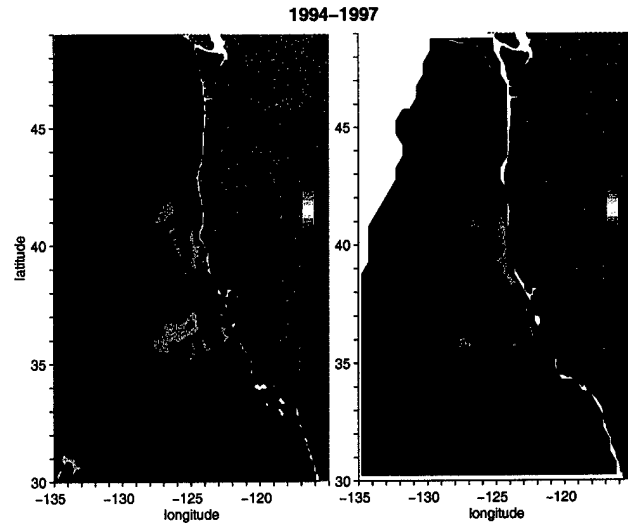
Figure 2. Model EKE fields from the gridded model
surface velocities (left) and binned (1/2 deg) drifters
(right).

tion and the statistical properties of the model flow fields have been compared with those of the STRATAFORM observations. The alongshore structure of the Eel River plume on the second nested model (with the highest resolution) has also been investigated.

## RESULTS

Strub and James [2000] describe the California Current System using data from the TOPEX, ERS-1, and Geosat satellite altimeters. Equatorward alongshore winds force the development of an equatorward upwelling jet in the spring and summer next to the coast. As the jet strengthens through the fall season, it moves offshore and develops strong meanders and closed eddies. Satellite eddy kinetic energy estimates show the corresponding offshore movement of high energy and its input into the Pacific interior. Near-surface drifters deployed in the California Current System show regions of high eddy kinetic energy near the coast which decrease offshore and to the south. Seasonal analysis of the drifter data also suggests a similar seasonal offshore movement of the EKE [Kelly et al., 1998].

The seasonal development of the POM/PWC model SSH is qualitatively similiar. Two month means computed from the the 1994-1997 model time period show a winter SSH high next to the coast that moves offshore in March/April, as the low SSH upwelling signal develops next to the coast. The low expands offshore in spring-summer and separates from the coast in July/August, moving farther offshore as a nearshore high begins to develop at the coast. In comparison to the similar 2-month mean SSHs from TOPEX/ERS, the model features appear to separate more quickly from the coast and lead the altimeter data by 1-2 months.

The 4-year (1994-1997) mean model SSH field is shown in Fig. 1. In general, the SSH contours show slow, south-eastward moving flow, as expected. One of the strongest features, however, is a strong offshore-onshore meander near Cape Mendocino (39°-41°N). Note also the onshore-offshore flow north and south of Monterey Bay (36°-37°N). This feature is not apparent in dynamic heights calculated from climatological temperature and salinity fields [Levitus and Gelfeld, 1992], nor in the mean

height field constructed by Kelly et al. [1998]. Likewise the onshore/offshore flow, north/south of Monterey Bay, does not appear in the fields of Kelly et. al., or the more well-sampled CalCOFI dynamic height fields of Lynn and Simpson [1987]. A comparison with the depth contours suggests that this flow is strongly linked to the bottom topography of the Mendicino Ridge [Righi et al., 1999].
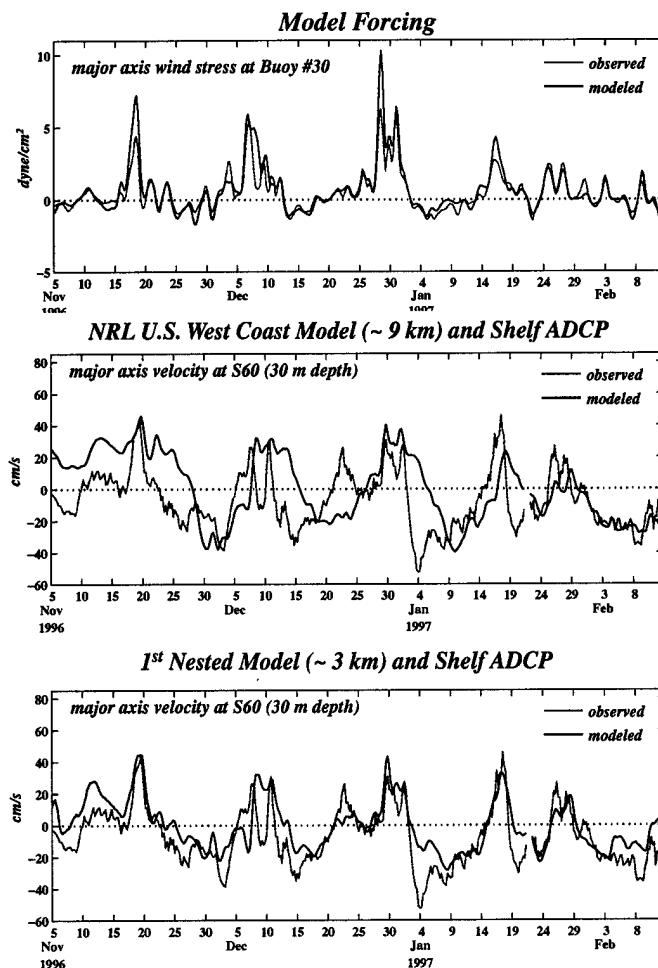
The effect of the strong onshore flow at 39°N can also be seen in the eddy kinetic energy fields from the model velocities and simulated drifters (Figure 2). Both fields show regions of high variability close to shore from 35°-43°N, and in offshore regions north of Cape Mendocino and south of San Francisco. Offshore at 38°N there is a strong low in EKE. In contrast, TOPEX EKE fields have a high in EKE centered at 38°N, 127°W. We believe that overly strong topographic steering causes the model velocity fields to take a semi-permanent path in this region that confines most of the kinetic energy to the mean, limiting the energy in the eddy field.

Besides comparisons to the altimeter data, the model surface current fields were used to advect clusters of drifters. The paths of these clusters were used to derive the vorticity along the path of the cluster, using the methods of Okubo and Ebbesmeyer [1976], a preliminary step in calculating vertical velocities. Comparison to values of vorticity from the model fields allowed improved tests of the reliability of the method, as presented by Righi and Strub [2000].

On smaller scales, the results of Shearman et al. [1999, 2000a, 2000b] provide a characterization of the vertical velocity fields associated with mesoscale features. These can be compared to similar model fields. In addition, Shearman et al. identify two types of eddies in the California Current - the surface cyclonic eddies associated with meanders in the jet and the deep anticyclonic eddies that may be associated with the undercurrent. Realistic model fields should produce similar structures.

Finally, the nested models (3 km and 1 km grids) have been successfully used to improve the velocity fields of the 9 km NRL model. Using the same model wind forcing (Figure 3, top) as in the NRL model, the 3 km resolution model exhibits many features of the observed strongly wind-forced shelf flow regime. Good agreement is found between the amplitude and time variability of the 3 km model currents and the observed currents on the shelf at 50m depth (Figure 3, bottom). By contrast, the coarser 9 km resolution NRL U.S. West Coast Model does not as accurately capture the observed flow variability at the shelf mooring site Figure 3, middle) [Pullen, 2000; Pullen and Allen, 2000a]. The 1 km resolution model provides increased resolution of the interaction between the shelf flow and the Eel River plume, which has significant alongshore variability as it progesses up the coast [Pullen and Allen, 2000b].

As part of the nested model study, Julie Pullen ran the NRL model independently from the NRL efforts, to provide boundary conditions for the nested models. In the process of doing so, she corrected an "error" in the NRL code, which neglected to remove the background density structure (a fairly well-known problem in models with vertical "sigma coordinates"). She communicated this to the NRL modelers. After presenting the analysis of the NRL model EKE and mean SSH fields (Figure 1, from Righi et al. [2000]), other versions of the PWC model were found to produce mean SSH fields that differ substantially from Figure 1. It was discovered that these versions of the model code had not corrected this problem. The uncorrected code was being used at NRL and Monterey (FNMOC). The output fields from the various models have now been standardized to include the correction, largely due to the efforts carried out within this funded ONR project in collaboration with John Kindle at NRL.

## Model Forcing



## NRL U.S. West Coast Model (~ 9 km) and Shelf ADCP



## 1st Nested Model (~ 3 km) and Shelf ADCP



*Figure 3. Model and measured wind forcing (top) . Measured 30m velocity over the shelf (50m depth) compared to the NRL 9 km model (middle) and the intermediate (3 km) nested model (bottom).*

## IMPACT/APPLICATIONS

The Navy is developing this relocatable regional model for global operational use. The same model has been planned to be used as NOAA's operational coastal ocean forecast model off the U.S. west coast. Results from this investigation have already identified a potentially serious problem in some of the versions of the model implementation (previous paragraph), which have now been corrected. The comparison between model fields, altimeter and in situ fields is continuing under separate funding, with an expanded range of models. This activity will be proposed to continue under NOPP funding, in a proposal presently being prepared. The eventual outcome of this activity will be a set of models, with output fields that are better understood in terms of their realism in simulating ocean circulation. Fields from these models and their successors will be used by the Coast Guard for search and rescue efforts, by fisheries managers, and many others, including academic researchers. The ongoing efforts to compare the model output fields to measured fields, begun in this project, will help quantify both the model and observation error fields. Estimates of these errors are vital to improved models that assimilate the observations.

## TRANSITIONS

The model and its successors will be used operationally by several agencies. The results from our validation efforts will provide estimates of model and observational uncertainty.

## RELATED PROJECTS

1. John Kindle and coworkers are using the NRL regional model as the basis for ecosystem models and optical models at NRL.
2. A similar model evaluation using altimeter data will be proposed as part of a West Coast NOPP proposal, testing a wider variety of models.
3. Results from this study will be communicated to those modeling and observing the California Current in the US GLOBEC North-East Pacific study, in which Strub and Barth are PI's.
4. John Allen is conducting high resolution modeling of the shelf region in the northern California Current region as part of CoOP and NOPP projects.

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In this project, we have evaluated the performance of the regional numerical circulation model in use by the U.S. Navy at NRL, as applied to the circulation of the California Current. We have also used the fields generated by that regional model as boundary conditions for very high resolution nested models of smaller coastal regions. The mean model surface height field has been compared to the expected climatology from several sources. A strong meander around Cape Mendocin was identified as unlike the climatology. The seasonal changes in the height field and EKE has been compared to similar fields from satellite altimeters. The model seasonal development is similar to the real ocean, but the seasonal jet in the model appears to leave the coast earlier in the year than in the altimeter data. This work is continuing under other funding. The nested models have been implemented and have been shown to improve agreement in comparisons to moored current meter observation.

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