Numerical Hindcasts of the California Current

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LONG-TERM GOALS

The long-term goal of this research is to support the Navy in the development of a reliable ocean modeling and prediction capability for eastern boundary current regions.

OBJECTIVES

The objectives of this project were (1) to carry out and extensively verify a numerical model hindcast of the California Current, and (2) to evaluate and apply digital filter initialization (DFI) as a diagnostic tool in numerical ocean prediction.

APPROACH

A numerical simulation of the California Current was carried out using the DieCAST regional model. The DieCAST model is a z-level primitive equation model that uses a fully conservative fourth order space finite difference scheme on a pair of staggered and co-located computational grids (Dietrich 1997). As a result, the model has high computational accuracy and especially low numerical dispersion (Sanderson 1998; Sanderson and Brassington 1998). Both of these properties are essential for an accurate simulation of fine scale processes in the coastal ocean and were found to be critical for simulating and explaining the observed behavior of eddy kinetic energy in the California Current. In the diagnostic studies, digital filter initialization (DFI) was successfully tested and refined as a diagnostic tool for ocean analysis using a variety of synthetic data with known properties. The method was then used to determine the 3-dimensional circulation and vertical velocity in several cold filaments observed in the California coastal transition zone.

WORK COMPLETED

During FY00 and FY01 we contributed to the advancement of coastal ocean modeling in several ways. First, we carried out a 5-year numerical simulation of the California coastal region using the DieCAST ocean model forced by a climatological annual cycle of wind stress. The simulation achieved a considerable level of realism (Miller et al. 1999) and lead to a new interpretation of the observed evolution of surface eddy kinetic energy (EKE) in the California Current (Haney et al. 2001). Second, we evaluated digital filter initialization (DFI) as a diagnostic tool in the ocean and we successfully applied the method to hydrographic observations in the ocean. These efforts resulted in the completion of three diagnostic studies, two in the California Current (Haney and Hale 2001; Shearman

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14. ABSTRACT
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et al. 2000) and one in the Alboran Sea (Viudez et al. 2000). Finally, in our collaborative studies of the Mediterranean Sea, we completed an analysis of mesoscale features in the Western Mediterranean detected by SAR imagery (Font et al. 2001), we completed a theoretical study of the stability of the global thermohaline circulation to stochastic resonance (Velez-Belchi et al. 2001), and we have several additional numerical modeling studies in progress at the present time. Vicente Fernandez, a doctoral student at Universitat de les Illes Balears (UIB), Spain, who visited NPS this summer, is carrying these out.

In preparation for a California Current hindcast, we have processed the 12-hourly surface wind stress from the operational runs of the MM5 atmospheric model from October 1998 to September 2000. These, and similar surface stresses from the COAMPS reanalysis fields (J. Kindle, NRL-Stennis), will be used to force the hindcast experiment. Such non-hydrostatic operational numerical prediction models accurately depict supercritical atmospheric flows that commonly occur around coastal points and capes (Burk et al. 1999). The surface wind stress of such flows represents an important forcing of the coastal ocean that we plan to hindcast. The numerical hindcast is specifically designed to investigate physical processes, and numerical modeling issues, related to the prediction of mesoscale variability observed in the California coastal region. This includes variability directly forced by the wind and that which occurs spontaneously as a result of flow instability or interaction with topography.

RESULTS

In our diagnostic studies, we have shown that one is able to diagnose accurately the 3-dimensional circulation and vertical velocity in the ocean by using the dynamic initialization technique of digital filter initialization (DFI). We verified the DFI method, and successfully applied it to synoptic hydrographic data from the CTZ program in the summer of 1988 (Haney and Hale 2001) and the EBC program in the summer of 1993 (Shearman et al. 2000). Figure 1, from Haney and Hale (2001), shows one of the main results of our diagnostic studies. It shows the three-dimensional circulation in an observed, offshore-directed California coastal jet. The upper ocean circulation associated with the jet is clearly seen to be both confluent (isobars becoming more closely spaced in the downstream direction) and convergent (ageostrophic velocity vectors). The strongest vertical velocities, of order 10m/d at 100m, are associated with meanders in the otherwise straight jet. This type of meander-induced vertical motion is consistent with that expected from the conservation of potential vorticity, and it is similar to that found in Gulf Stream meanders (Bower and Rossby 1989; Lindstrom and Watts 1994). In this study DFI was shown to be an especially valuable tool for diagnosing the circulation in realistic mesoscale features in which the Rossby number is not small and the scales of variability are close to the Rossby radius.

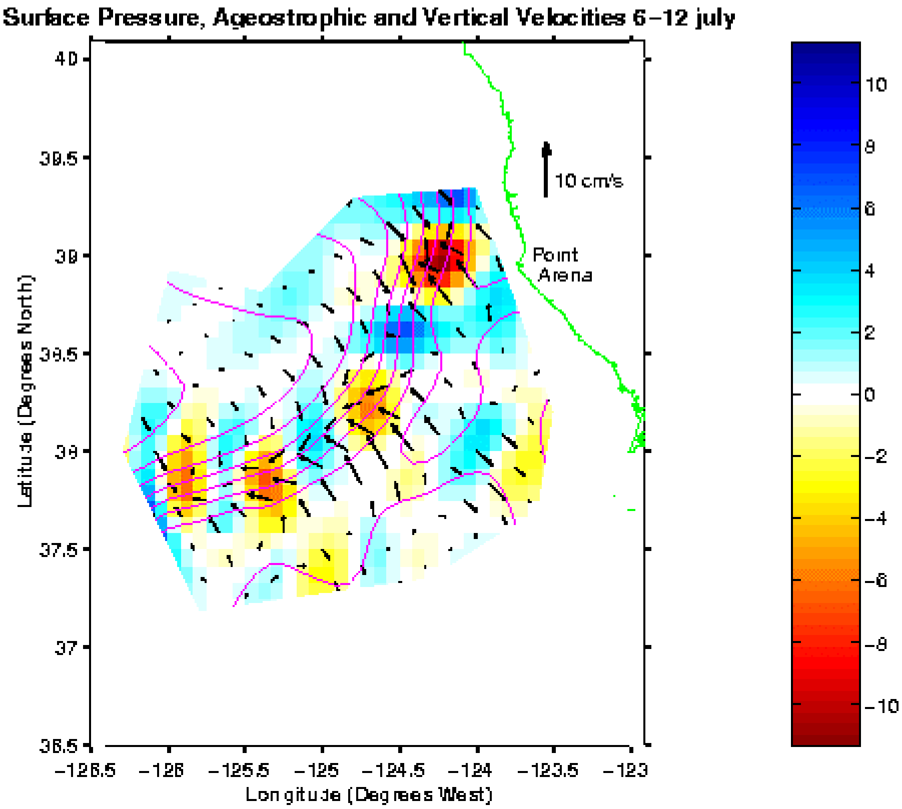

Figure 1. Surface height field (magenta isolines with contour interval of 4 cm), ageostrophic velocity at the surface (arrows with scale on the right) and vertical velocity at 90 m (color bar in m/d). The results are for the CTZ survey during July 6-12, 1988. From Haney and Hale [2001].

Figure 2, from Haney et al. (2001), shows one of the results from our California Current simulation using monthly mean climatological wind forcing. With such forcing, the model reproduces many of the main features of the observed annual cycle of the California Current including the strengthening of the coastal jet in spring and the weakening of the jet in autumn and winter. Coastal eddies in the simulation form primarily off the major headlands, especially Cape Mendocino and Point Arena, during the upwelling season. As a result of this eddy development, a region of maximum eddy kinetic energy (EKE) migrates westward from the coast on a seasonal time scale. This seasonal development, in which the EKE builds up at the coast, propagates slowly offshore, and subsequently decreases at the surface west of about 127W in the simulation, is in close agreement with the most recent satellite observations (Kelly et al. 1998, Strub and James 2000). We have recently shown in our model simulation that as the EKE propagates offshore, it spreads vertically into the deep ocean by means of a nonlinear transformation of kinetic energy from the vertical shear (baroclinic) current to the vertical mean (barotropic) current (Haney et al. 2001). Such an energy transformation is predicted to occur as a part of the natural up-scale transfer of kinetic energy in quasi-geostrophic turbulence (Salmon 1998). We consider this result to be a most significant accomplishment. This is not only because it explains the satellite observations of near surface EKE, but because of its broad implications about the dynamics and role of eastern boundary current regions in supplying EKE to the deep ocean and the need for numerical models of the coastal oceans to simulate the process accurately. Indeed, this offshore (and downward) propagation of EKE is considered to be a new and robust metric for comparing and validating west coast regional models (e.g. Penven et al. 2001).

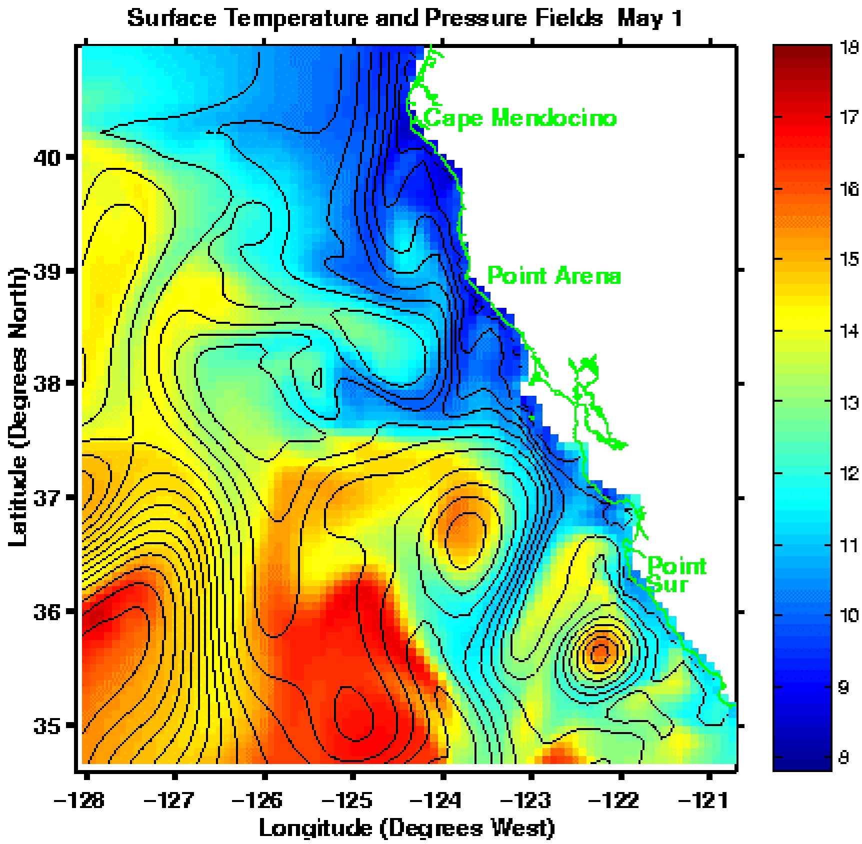

Figure 2. Sea surface temperature (color in °C) and sea surface heights (2 cm contour interval) on May 1 of the 5th year of the numerical simulation. From Haney et al. [2001].

IMPACT/APPLICATIONS

Our validation and use of DFI as a diagnostic tool in the ocean will have a significant impact in diagnostic ocean studies and numerical ocean prediction. Our model based interpretation of the offshore propagation of EKE in the California Current in terms of the barotropization of the eddy field as it evolves offshore will have a major impact in both physical oceanography and ocean modeling. For example, the phenomenon will turn out to be present in other areas of the ocean as well (e.g. other eastern boundary currents, the separated Gulf Stream, etc.). In addition, the modeling requirements to simulate this barotropization process correctly, namely accurate (higher order) numerical methods and a highly inertial model with low numerical and physical viscosity, will be broadly acknowledged in ocean modeling. Thus, our project has produced a new diagnostic tool, and a new and especially valuable metric, for the ocean modeling community.

TRANSITIONS

Our research in the California Current is in broad support of the efforts at FNMOC (M. Clancy) and NRL-Stennis (J. Kindle) to develop a real-time ocean analysis and forecasting capability for this region. Our collaborative studies in the Mediterranean Sea are in broad support of the efforts at NRL-Monterey (R. Hodur) to develop the coupled version of COAMPS. This support manifests itself in close coordination, and timely information exchange on such topics as model properties, experimental set-up, forcing and verification data, regional modeling difficulties, comparison and exchange of results, methods of model verification, and so forth.

RELATED PROJECTS

I have collaborated with J. Barth and Kipp Searman (OSU) to use DFI with the EBC synoptic hydrographic data and with Julie Pullen and others at NRL-Monterey to develop the Navy's high-resolution coastal ocean model (NCOM) in the Mediterranean Sea. I am also collaborating with J. Tintore (UIB, Spain) in diagnostic studies of mesoscale variability in the Alboran Sea and in modeling the inter-annual variability in the Mediterranean Sea. Finally, I am collaborating with J. McWilliams (UCLA), J. Kindle (NRL-Stennis) and T. Strub (OSU) in model-data inter-comparison studies off the West Coast of North America.

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