1.5 SENSITIVITY OF A NAVY REGIONAL OCEAN MODEL TO HIGH-RESOLUTION ATMOSPHERIC MODEL AND SCATTEROMETER WIND FORCING

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1. Introduction

As the focus of Navy attention shifts to littoral regions, higher resolution and re-locatable nested models have been developed to improve shallow-water operations. One of the scientific and technical challenges is to determine how much detail and accuracy in ocean wind data is needed to meet operational requirements. As the focus of Navy attention shifts to littoral regions, higher resolution and re-locatable nested models have been developed to improve shallow-water operations, including better search planning and tactics development in range and azimuth dependent environments. In the coastal and shallow water environments, mesoscale oceanographic processes (~2-50 km horizontal space scales and ~2-10 day time scales) over the continental shelf is influenced by the variability of atmospheric forcing (Batteen, 1997). One of the scientific and technical challenges is to determine how much detail and accuracy in ocean wind data is needed to meet operational requirements.

As the resolution of Navy ocean models approach and/or exceed that of the satellites and atmospheric models providing the wind data, there exists a need to assess the impact of satellite/model wind data on these models. The focus of this study is on the wind-forced coastal ocean regime. This study examines the impact of variable atmospheric model resolution wind forcing and synthetic scatterometer data assimilation on a regional ocean model with a fixed resolution. The primary goals of this research are to evaluate: 1) How high-resolution atmospheric model winds make a difference for the coastal regions of a regional ocean model, and 2) The impact of synthetic scatterometer data on both the atmospheric models and ocean models with emphasis on the geographic locations of the differences.

2. Ocean Models

The Navy's Pacific West Coast (PWC) model is based on the Princeton Ocean Model - POM (Blumberg and Mellor, 1987; Mellor, 1996). The PWC is a three-dimensional, 30 sigma layer, free surface model based on the primitive equations for momentum, salt, and heat. The model is configured on a 1/12degree spherical grid extending from the coast (116° W) to 135° W and 30° N to 49° N. Composite multi-channel sea surface temperature (MCSST) for surface heat forcing and monthly salinity climatology are provided by the Generalized Digital Environmental Model (GDEM). The Navy's Digital Bathymetric Data Base (DBDB5) provides ocean depths at oceanic geographic positions. Sources of fresh water include monthly varying climatological fresh water run-off from seven major rivers that drain into the domain. Turbulence closure is provided by the turbulence closure submodel developed by Mellor and Yamada (1982), while the Smagorinsky (1963) formula is used for horizontal mixing.

For open boundary conditions, the PWC is coupled to the Naval Research Laboratory (NRL) Layered Ocean Model (NLOM) with a nudging/relaxation scheme for boundary conditions along the northern, southern and western boundaries. NLOM is a multi-layer, free surface, hydrodynamic primitive equation ocean model with full-scale bottom topography in the lowest layer. NLOM is forced by 6-hourly NOGAPS wind stress fields produced at FNMOC.

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TOPEX/Poseidon and ERS-2 altimeter data are assimilated into the NLOM using the optimum interpolation (OI) of Sea Surface Height (SSH).

3. Atmospheric Models

Ocean circulation model wind forcing is provided by the Navy Operational Global Atmospheric Prediction System (NOGAPS) and the Coupled Ocean-Atmospheric Mesoscale Prediction System (COAMPS). NOGAPS is a global spectral model (GCM) consisting of 160 spectral waves and 18 vertical levels to 10 mb. The vertical coordinate is a hybrid system that follows the terrain at low levels and contains pressure surfaces at upper levels. Model physics include long-wave and short-wave radiation, boundary layer processes, and stable and convective cloud and precipitation parameterization (Rosmond et al., 2002). In this study, NOGAPS forcing drives NLOM and provides boundary and initial conditions for COAMPS.

COAMPS was developed by the Naval Research Laboratory based on the Klemp and Wilhelmson (1978) atmospheric model. Operational at FNMOC since July, COAMPS is a 3-D, limited area, relocatable, multi-nested, non-hydrostatic model composed of an objective analysis scheme incorporating data quality control (Baker, 1992; Barker, 1992), and a multivariate optimum interpolation (MVOI) analysis (Baker, 1992; Goerss and Phoebus, 1992). COAMPS includes predictive equations for momentum, the non-dimensional pressure perturbation, the potential temperature, and mixing ratios of water vapor, clouds, rain, ice and snow. In this study, the MVOI analysis in COAMPS is replaced by two-dimensional multiquadric interpolation (Nuss and Titley, 1994).

For initialization and the required lateral boundary conditions, COAMPS is designed for nesting within NOGAPS. The nesting is accomplished by imposing NOGAPS fields on the outer grid points of the COAMPS grid in a one-way interactive mode. The grid spacing is reduced by a factor of three between each nest that allows the COAMPS grid to telescope down to resolutions of less than 10 km in areas that require high resolution. In this study, the COAMPS domain is located over the Western United States, from 90°W to 165°W longitude and 10°N to 65°N latitude.

4. Experiment Design

A series of experiments, each one of a 14-day duration, are performed to evaluate the sensitivity of a regional ocean model to low (NOGAPS) versus high-resolution (COAMPS) wind forcing including scatterometer data insertion into COAMPS using synthetic QuikSCAT observations. The winter period of 07-21 January 1999 was selected for this study based on the availability of verification field data and the atmospheric wind variability provided by the passing of winter weather systems through the model domain. Five ocean runs are conducted using wind stress forcing supplied by NOGAPS and COAMPS with variable horizontal grid spacing. Two additional COAMPS-45 km grid runs are conducted to compare the impact of the assimilation of real versus synthetic QuikSCAT. The fifth run includes the assimilation of synthetic scatterometer winds into the 45 km COAMPS grid used in run two. Runs six and seven are used for a comparison of the impact of synthetic QuikSCAT versus real QuikSCAT data on a coarser grid atmospheric model (i.e., COAMPS 45 km). A COAMPS analysis and eight three-hourly forecasts are generated twice a day (0000 UTC and 1200 UTC) for the 14-day study period resulting in 252 atmospheric model output files for each of the five experiment runs (for a total of 1260). The three-hourly NOGAPS wind stress data are provided by FNMOC on a Mercator grid, whereas COAMPS generates wind stress data using a Lambert conformal grid. For each experiment run, the three-hourly NOGAPS/COAMPS wind stress data are interpolated to the 1/12 degree (~10 km) PWC model Mercator grid using a Akima spline.

5. Synthetic QuikSCAT Data

The COAMPS 25 km wind stress fields are used to create the QuikSCAT synthetic data because they approximate the resolution of QuikSCAT observations and have similar errors (~ +/- 20 degrees in wind direction and 1.4 m/s and 2 m/s in wind speed for QuikSCAT and COAMPS, respectively. The SOAP software generates ground tracks and subsatellite points with the required 25 km separation along the satellite heading. Using each subsatellite position as a node, 72 satellite swath points are symmetrically created around the node on a line perpendicular to the satellite heading. The 72 swath points have a 25 km separation and produce a 1800 km synthetic QuikSCAT swath. All distance, longitude and latitude values are calculated using the World Geodetic System ellipsoid of 1972. COAMPS 25 km wind stress data are matched to the synthetic track points by the “nearest neighbor” method and inserted into a 45 km COAMPS domain as observations using a plus/minus time window of 2.5 hours around the analysis times of 0000 UTC and 1200 UTC.

6. Field Observations

The period of this study was selected to take advantage of the hydrographic data collected during a California Cooperative Fisheries Investigations (CalCOFI) Central California cruise between 06 and 20 January 1999. Using a Seabird 911 plus conductivity, temperature and depth (CTD) instrument, the Research Vessel Point Sur performed 159 CTD casts and 101 XBT drops along with continuous wind observations and Acoustic Doppler Current Profiler (ADCP) data collection. The ship’s track was designed to maximize cross-shore measurements. The ADCP measurements start at 20 m depth with a maximum depth of 412 m. CTD and XBT data collections start at 1 m depth with a 1 m separation between levels.

NOAA operates two high frequency (HF) radar sites on the shore of Monterey Bay, one near the center of the Bay at Moss Landing, and one at the southern end of the bay at Pacific Grove. These instruments are of the CODAR design and provide useful coverage to ~22 km offshore. The CODAR system computes the surface current velocity with a horizontal range resolution of 2 km and RMS errors of +/- 2 to 3 cm/s.

The National Data Buoy Center (NDBC) maintains an array of moored buoys on the Pacific West Coast. The parameters reported include wind speed and direction. For model-to-observation comparisons, the wind speed data from twenty-three buoys is converted to wind stress. Continuous wind measurements are six 10-minute average values of wind speed (m/s) and direction (in degrees clockwise from North) reported each hour. NDBC also uses Acoustic Doppler Current Profilers (ADCP) to measure current velocity from a limited number of stations. Currently, three NDBC stations measure ADCP data: stations 46023 (Point Conception, CA), 46054 (Santa Barbara, CA) and 46062 (Point San Luis, CA). Data are in the form of both eastward and northward current velocities for 20 depth levels. The first level occurs at 25 m depth and the last at 329 m depth with a 16 m separation between levels.

The Monterey Bay Aquarium Research Institute (MBARI) operates three moorings to obtain weather and oceanic data in Monterey Bay. The M1 and M2/M3 moorings are located in 1000 and 1800 m of water, respectively. The nearshore M1 mooring lies in the path of a persistent upwelling plume and is sensitive to changes in the upwelling regime. The offshore M2 mooring lies at the eastern margin of the California Current. M3 is located near the mouth of Monterey Bay. Buoy deployments are an ATLAS-like mooring at the M2/M3 sites and a PROTEUS-like mooring at M1. The primary difference between ATLAS and PROTEUS is that the latter has a four-leg tower and bridle to accommodate deployment of an ADCP. ATLAS collects and stores meteorological and ocean temperature information once every ten minutes. The ADCP is programmed to take a measurement once every 15 minutes and has a bias typically on the order of 0.5 to 1.0 cm/s.

7. Results

There is significant improvement with increasing atmospheric model resolution in producing realistic structures (e.g., expansion fans) in coastal areas with variable topography. The COAMPS runs provide enhanced structure compared to NOGAPS and other COAMPS runs with increasing horizontal grid resolution. Quantitatively, the COAMPS wind stress and wind stress curl values are in agreement with aircraft observations. Atmospheric model comparisons to buoy data show good agreement with a tendency for NOGAPS and COAMPS to underestimate and overestimate wind stress amplitude, respectively, with a small direction bias to the right of real wind stress. The insertion of synthetic QuikSCAT data in to the COAMPS 45 km run produces a statistical difference but no significant difference in wind stress, wind stress curl and ocean current. This result implies that higher spatial and/or temporal resolution (i.e., multiple QuikSCAT satellites with improved sensors) is required for the satellites to have a significant impact. This also implies that the atmospheric model has sufficient skill in coastal areas using currently (i.e., DMSP SSM/I, etc) available observations.

The ocean model runs have the typical climatological features and variability. Comparisons to CalCOFI observations imply that ocean variability increases with increasing atmospheric model horizontal grid resolution. In comparisons of model current to ADCP buoys, the model currents usually underestimate observed current amplitude. Model current direction generally reflects the variability of CalCOFI data and increase with increasing atmospheric model resolution. Similarly, model currents had improved agreement with CODAR observations with higher resolution COAMPS runs. In comparison to buoy data, the direction of the model currents often follow the offshore flow, sometimes in opposition to the observed direction. Typical offshore ocean features (e.g., California/Davidson Currents) in the model may not be discernible from variable features attributed to local wind forcing, bottom topography, baroclinic tides, transient coastal waves, and non-hydrostatic model physics.

8. Conclusion

The “one size fits all” approach, in which all regions are run with the same resolution, may not be an efficient use of computer resources and the demonstrable benefits of increasing resolution may vary spatially and temporally. Also, typical fast moving storm systems, the land-sea breeze system and their associated winds may not be sampled properly in both space and time. Note that the problem of ‘”land contamination” in the ocean model due to caused by the interpolation of atmospheric fields to the ocean model grid still must be addressed. The consequence is that the multi-day composite ocean winds derived from satellites are not optimal for use in driving a high-resolution coastal ocean model. As a result, it is recommended that the Navy continue its current approach of developing relocatable, nested, high-resolution atmospheric and ocean models. These should include development of multiple scatterometer satellite platforms with emphasis on the development of microwave sensors capable of 1-10 km resolution, and non-hydrostatic ocean models to compliment the non-hydrostatic atmospheric models such as COAMPS.

9. References

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