Air/Ocean Model and Prediction System Development

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LONG-TERM GOAL

The goal of this project is to develop a fully coupled mesoscale atmosphere-ocean prediction system that can be used over any given area of the world. This goal is to be accomplished by coupling a full-physics mesoscale ocean model to a mesoscale atmospheric forecast model; developing, testing, and evaluating software for the necessary supporting infrastructure; and by leveraging related programs to develop an ocean data assimilation capability. This prediction system will be the cornerstone for basic and applied research to study forecast problems for which coupling may be important, and it will also be transitioned to operations to address those situations for which coupling is found to make a significant positive impact on mesoscale forecasts of the atmosphere and/or ocean.

OBJECTIVES

The objectives of this project are:

1. Study the methodologies for, and the impact of, coupling a mesoscale ocean data assimilation system to a mesoscale atmospheric data assimilation system. This involves studies of issues that include, but are not limited to: one-way vs. two-way interaction, resolution, frequency of coupling, and the relative importance of air-ocean exchanges between the atmosphere and the ocean.

2. Test and validate the coupled prediction system over a number of areas and over a variety of atmosphere/ocean phenomena. We will establish the conditions for which coupling is important, and whether the system needs to be loosely- or tightly-coupled. Furthermore, we will establish performance metrics to measure the quality of the atmosphere and ocean analyses and forecasts.

3. Develop techniques to ensure that the coupled ocean-atmosphere system is relocatable to any region over the world. Our coupled system will use global databases for coastlines, bathymetry, etc., to allow for use over any geographical area, and we will develop techniques to incorporate tendencies from a global ocean model into our mesoscale ocean model.

APPROACH

Our approach is to build on the infrastructure that already exists in the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS™; Hodur 1997) and to use this infrastructure for our scientific experiments. The atmospheric component of COAMPS™ has reached a level of maturity such that it is routinely used for numerous basic and applied research topics as well as for operational

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14. ABSTRACT
The goal of this project is to develop a fully coupled mesoscale atmosphere-ocean prediction system that can be used over any given area of the world. This goal is to be accomplished by coupling a full-physics mesoscale ocean model to a mesoscale atmospheric forecast model; developing, testing, and evaluating software for the necessary supporting infrastructure; and by leveraging related programs to develop an ocean data assimilation capability. This prediction system will be the cornerstone for basic and applied research to study forecast problems for which coupling may be important, and it will also be transitioned to operations to address those situations for which coupling is found to make a significant positive impact on mesoscale forecasts of the atmosphere and/or ocean.

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mesoscale forecasts using resolutions as low as 1-5 km. In a related program, a 3-dimensional MVOI analysis and quality control algorithms have been developed to construct analyses of the ocean temperature, salinity, currents, sea surface height, and ice. In another related program at NRL Stennis (NRL SSC), the Navy Coastal Ocean Model (NCOM) has been developed for use as a mesoscale ocean model. NCOM is a hydrostatic ocean model that predicts the circulation and thermodynamic properties of the ocean using sigma-levels, z-levels, or a combination of these.

Testing of the coupled system has focused initially on the Mediterranean Sea with a special emphasis on the Adriatic Sea, to take advantage of the upcoming Adriatic Circulation Experiment (ACE). We will experiment in other areas of the world, as well, to demonstrate the relocatability of the coupled system and to replicate a wider range of phenomena. In time, we will expand our research into other areas of the world and we will use as many additional special datasets (i.e., those not routinely available in near-real time) as is practical for our demonstration and verification studies.

Our approach is divided into three components: (1) atmospheric reanalyses, to reconstruct the meteorology over specific areas of interest; (2) ocean model spin-up, to test the effects of high spatial and temporal resolution COAMPS™ reanalyses forcing fields on NCOM predictions; and (3) system development and integration, to build a system that is robust, flexible, and efficient.

WORK COMPLETED

The following work was performed during FY 02 in the three components of the project.

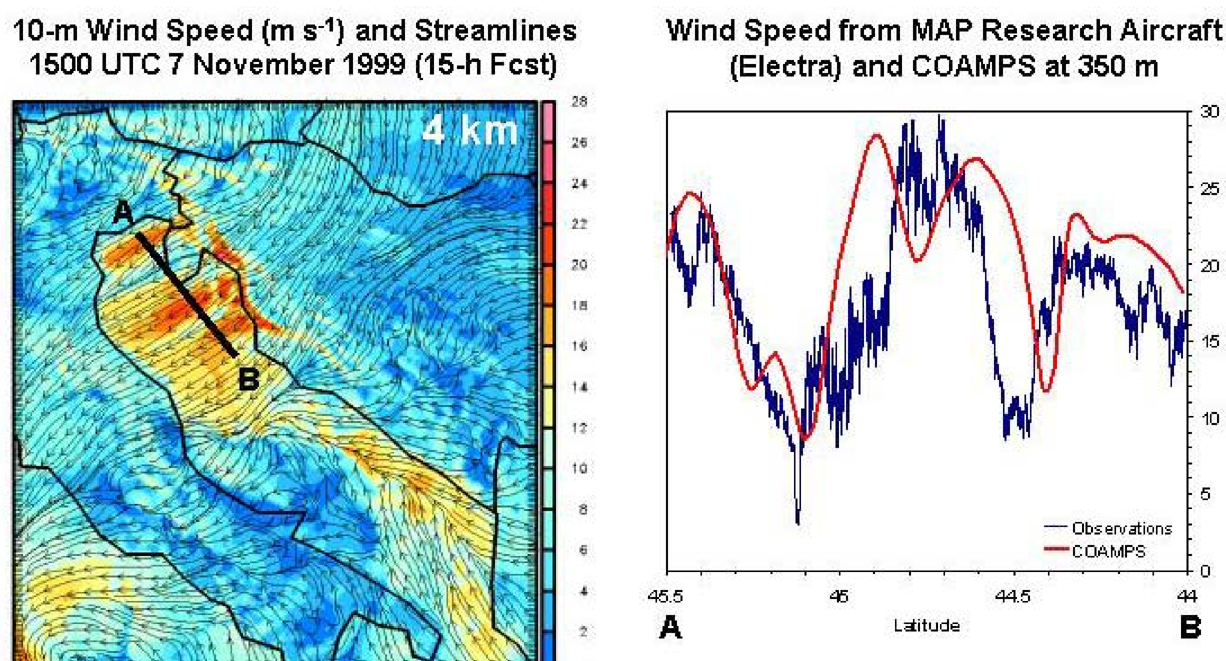
1. Atmospheric reanalyses. COAMPS™ reanalysis fields, with hourly output, are continuously being generated for the Mediterranean Sea, the eastern Pacific, and the Adriatic Sea. The Mediterranean reanalysis uses a doubly-nested grid, with grid spacings of 81 and 27 km; the eastern Pacific reanalysis uses a triply-nested grid, with grid spacings of 81, 27, and 9 km; and the Adriatic Sea reanalysis uses a triply nested grid, with grid spacings of 36, 12, and 4 km. Over 3 years of integration has been performed so far for the Mediterranean Sea area, over 2 years for the and eastern Pacific area, and approximately 1-1/2 years for the Adriatic Sea area.

2. Ocean model spin-up. The surface forcing fields constructed in (1), were used to force NCOM to study the effect of high spatial and temporal resolution forcing on the ocean dynamic and thermodynamic structure of the Mediterranean Sea and the Adriatic Sea. These studies have provided us a large database that we will use to perform extensive analyses of the results.

3. System development and integration. All ocean software components of COAMPS™ were incorporated into the COAMPS™ configuration management system. These components include programs for pre- and post-processing of ocean grids, bathymetry, and observations; the 3D multivariate optimum interpolation (MVOI) ocean analysis; interfaces between the 3D MVOI and NCOM; and the Navy Coastal Ocean Model (NCOM), including a general flux coupler.

RESULTS

1. Atmospheric reanalyses. Long-term atmospheric reanalyses have been performed for a number of regions including the Mediterranean, the eastern Pacific, and the Adriatic. The results of the atmospheric reanalyses indicate that more accurate spatial and temporal variations of meteorological parameters (e.g., surface stress, temperature) are predicted by using the high-resolution fields generated in this study, as opposed to results found with coarser grid models or from climatology. Resolutions from grids using a horizontal spacing of 27 km or less capture many local low-level wind phenomena, such as topographically-forced winds, and winds driven by differences across the land-sea boundary and diurnal effects. Increasingly higher resolutions of atmospheric forcing demonstrate the ability to simulate pronounced coastal effects associated with flow around smaller-scale capes, bays, and inlets. Validation of these reanalyses against observational data is on-going in this and other projects. As an example of the quality of the reanalysis in the Adriatic region is shown in Fig. 1. The reanalysis winds produced at a horizontal resolution of 4 km indicate detailed structure in the 10-m winds associated with a bora event at 1500 UTC 7 November 1999 (Fig. 1a). The local topography forces a series of local jets and wakes in the near surface wind field that have important implications for the Adriatic circulation. These jets and wakes are simulated with remarkable accuracy when compared with wind speed observations at 350 m obtained from the NCAR Electra during the Mesoscale Alpine Programme (MAP).



(a) (b)

Figure 1. Simulation and observations of a bora event over the Adriatic. (a) Wind speed (m s^{-1}) and streamlines at 10 m from a 15-h COAMPS™ simulation valid at 1500 UTC 7 November 1999. (b) Wind speed (m s^{-1}) from the NCAR Electra (blue) and COAMPS™ simulation at 350 m along the A-B flight track shown in (a).

2. Ocean model spin-up. Two separate studies were performed with NCOM. The first examined the sensitivity of the model solution to spatial and temporal changes to the atmospheric forcing, and the second examined the response of the northern Adriatic circulation to the Bora wind event.

a. NCOM sensitivity to differing spatial and temporal atmospheric forcing

Ocean model spin-ups were performed with NCOM for six cases. Three cases used 81-km COAMPS™ forcing at 1-, 6-, and 12-h intervals, and the other three cases used 27-km COAMPS™ forcing, also at 1-, 6-, and 12-h intervals. The spin-up was run for a 2-year period with the atmospheric forcing repeated from Oct. 1, 1998 - Sept. 30, 1999). Although the COAMPS™ surface stresses were used directly, the heat flux was calculated from the bulk formula using the COAMPS™ 10 m temperature and winds, and the analyzed SST. For these tests, NCOM used a horizontal resolution of 6-km and with a grid size of 576 × 288 and 41 levels. Also, the depths of the top and bottom layers were 2m and 4000 m, respectively. The Smagorinsky horizontal mixing scheme and the Mellor-Yamada 2.5 vertical mixing scheme were used.

We have evaluated the spin-up simulations that used 81-km forcing and 27-km forcing. For the winter season, the results from our simulations indicate that larger differences occur in the west Mediterranean (WMED) than in east Mediterranean (EMED) when the resolution of the forcing fields is changed. The strong and very active Mistral wind system in the WMED during winter period was better captured in 27-km forcing field and was the reason for the larger differences. During the summer season, substantial evaporation dominated the EMED using 27-km forcing fields, so the difference between the use of 27- and 81-km forcing was larger in the summer than in the winter season in the EMED. Our results also suggest that mesoscale features in the Mediterranean Sea, such as jets, and cyclonic and anticyclonic gyres, are better simulated using 27-km forcing as opposed to 81-km forcing. The use of 81-km forcing resulted in smoother and less intense features, when compared to observations.

We found significant differences when changing the temporal forcing of NCOM. With high-frequency atmospheric forcing (1-h), our results suggest better definition of features when compared to observations. However, the difference between 1- and 6-h forcing was significantly smaller than between 1- and 12-h or between 6- and 12-h forcing, suggesting that when applying atmospheric forcing over periods longer than 6-h, the forecast error may be increased significantly. The difference caused by temporal resolution of atmospheric forcing was more substantial in summer than in winter. This result may suggest a sensitivity of the summer evaporation over the Mediterranean Sea, prominent during this time of the year, to the frequency of atmospheric forcing. The errors in the salinity field due to the 12-h forcing resulted in unrealistic water mass structure in the EMED during the summer season.

b. Response of the northern Adriatic circulation to Bora wind event

A nested grid of 2 km resolution covering the Adriatic Sea was inserted into a 6 km NCOM grid covering the entire Mediterranean Sea. The 2 km nest received initial and lateral boundary values from a 2-year spin-up performed on the 6 km full-Mediterranean grid spin-up, and surface forcing from the Adriatic atmospheric reanalysis (described in the previous section on atmospheric reanalysis results). In two separate simulations, the Adriatic 2 km ocean model was forced with fields from the 4 km reanalysis and the 36 km reanalysis. The two ocean model simulations were validated using

ADCP observations from the northern Adriatic taken by the ONR-sponsored EuroSTRATAFORM program and the NRL Adriatic Circulation Experiment (ACE). The ADCP sites were separated by 125 km and represent an overlapping record of 125 days (28 January – 4 June 2001) . Both simulations reproduced the observed magnitude and direction of the mean and fluctuating 5 m current at the two sites very well. In addition, the simulations captured the observed barotropic nature of the mean and standard deviation at the NRL site. The simulations also matched the observed increase in correlation with wind through the water column at the NRL site.

An EOF analysis of ocean velocity maps at 5 m and 25 m depth reveals that the 4 km atmospheric forcing generated a double gyre circulation pattern in the northern Adriatic in response to the bora. The dominant mode of the 36 km forced ocean simulation does not have this prominent feature, which has been documented in observations and idealized modeling efforts. Though both simulations validated well against point measurements in the ocean, the superior representation of the bora winds afforded by the 4 km atmospheric reanalysis created a richer and more realistic circulation pattern in the ocean.

3. System development and integration. We have developed a flux coupler, and have used it to demonstrate the importance of using unfiltered atmospheric fluxes and stresses, and in using only over-water points when interpolating fluxes from the atmospheric grid to the ocean grid. This eliminates having the over-land fluxes and stresses (typically much larger than over-water values) from negatively impacting the ocean circulation and thermodynamic structure near the coast.

IMPACT/APPLICATIONS

The development of a fully-coupled atmosphere-ocean prediction system is considered to be the cornerstone for our studies of air-ocean research. An analogy can be drawn to the development of the atmospheric component of COAMPS™. This system is now used for a variety of basic research topics, such as topographic flows, fetch-limited flows, littoral phenomena, tropical cyclones, and convection. COAMPS™ is also used for applied research, including real-time forecasts for field experiments such as CALJET, LABSEA, and CBLAST. In addition, COAMPS™ has been transitioned to the Fleet Numerical Meteorology and Oceanography Center (FNMOC) for operational mesoscale forecasts for up to eight areas over the globe. It is expected that the development of a fully-coupled atmosphere/ocean COAMPS™ in this program would enable an expansion of the types of mesoscale studies that can be performed in 6.1, an expansion of the 6.2 applications of the system, and improved operational mesoscale forecasts. Finally, the COAMPS™ reanalyses will have a significant impact in the studies of air-ocean coupling. Fields with such high-frequency time and space variations over such a long time period (> 1 year) have never been used before in forcing ocean models. Our studies will reveal the importance of these mesoscale variations on the ocean circulation and thermodynamic structure and the impact that temporal ocean variations have on atmospheric forecasts.

TRANSITIONS

The fully-coupled COAMPS will eventually transition to 6.4 projects within PE 0603207N (SPAWAR, PMW-185) that focus on the transition of COAMPS and COAMPS-On Scene (COAMPS-OS™) to FNMOC, and the transition of the ocean data assimilation system for COAMPS™.

RELATED PROJECTS

The fully-coupled COAMPS™ will be used in related 6.1 projects within PE 0601153N that include studies of fetch-limited and orographic flows and atmospheric physics, and in related 6.2 projects within PE 0602435N that focus on the development of the atmospheric components (QC, analysis, initialization, and forecast model) of COAMPS™. The fields from our reanalyses over the eastern Pacific will be used by scientists at NRL SSC and at the Naval Postgraduate School within their joint National Oceanographic Partnership Program (NOPP), to study air-ocean coupling processes on the west coast of the United States.

REFERENCES

Hodur, R. M., 1997: The Naval Research Laboratory's Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS). *Mon. Wea. Rev.*, **125**, 1414-1430.

Teague, W. J., M. J. Carron, and P. J. Hogan, 1990. A comparison between the Generalized Digital Environmental Model and Levitus climatologies. J. Geophys. Res., 95 (C5), 7167-7183.

PUBLICATIONS

Hodur, R.M., J. Pullen, J. Cummings, X. Hong, J.D. Doyle, P. Martin, 2002: The Coupled Ocean/Atmosphere Mesoscale Prediction System. *Oceanography*, **15**, 88-98.