Air/Ocean Model and Prediction System Development

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LONG-TERM GOAL

The long-term 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 main objectives of this project are to:

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, 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 mesoscale forecasts using resolutions as low as 1-5 km. The atmospheric component of COAMPS contains

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14. ABSTRACT
The long-term 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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complex data quality control; a multivariate optimum interpolation analysis (MVOI) capability for winds and heights; model initialization; and a nonhydrostatic, multi-nested forecast model. 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. The 3D ocean MVOI and NCOM are the building blocks for the COAMPS ocean data assimilation system.

Testing of the coupled system will focus initially on the Mediterranean Sea. There are several reasons for this choice: (1) it is an important area for the U. S. military, (2) it is nearly an entirely closed basin, minimizing the need for lateral boundary conditions, (3) there are frequent periods of strong atmospheric forcing due to orographically driven mesoscale wind features (e.g., Mistral, Levante, Bora), and (4) there exists an abundance of data for atmospheric validation. Although there is sparse sub-surface data available in the Mediterranean Sea (common to all ocean areas), there have been a number of modeling and observational studies in the past, and a growing number that can be used in our future work. 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 particular, we will develop high resolution atmospheric reanalyses for the west coast of the United States and collaborate with the Naval Postgraduate School in studying the effects of coupling in this area, which is characterized by strong upwelling. We also plan to extend the testing to the Adriatic Sea and the Baltic Sea, in conjunction with field experiments that are being conducted in those regions. 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 four components: (1) atmospheric reanalyses, to reconstruct the meteorology over specific areas of interest; (2) ocean model spin-up, to test the effects of using the high spatial and temporal resolution forcing fields from the COAMPS reanalyses on NCOM predictions; (3) ocean data assimilation, in which we use the ocean 3D MVOI and NCOM as components of an intermittent ocean data assimilation cycle; and (4) system development and integration, to build a system that is robust, flexible, and efficient.

WORK COMPLETED

The following work was performed during FY 01 in the four components of the project:

1. Atmospheric reanalyses. Surface flux and surface stress reanalysis fields were generated for the Mediterranean Sea, the eastern Pacific, the Baltic Sea, and the Adriatic Sea. The atmospheric component of COAMPS was used to construct these fields and output them at hourly intervals. The Mediterranean reanalysis used a doubly-nested grid, with grid spacings of 81 and 27 km; the eastern Pacific and Baltic Sea reanalyses used a triply-nested grid, with grid spacings of 81, 27, and 9 km; and the Adriatic Sea reanalysis used a triply nested grid, with grid spacings of 36, 12, and 4 km. Over 2 years of integration has been performed for the Mediterranean Sea and eastern Pacific, and approximately 4 months of fields have been generated for the Adriatic and Baltic Sea areas.

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. This has provided us an extensive database that we will use to perform extensive analyses of the results. These fields will also be used as starting conditions for ocean update cycles.

3. Ocean data assimilation. The work completed in this component of this project was done in strong collaboration with the project titled: "Ocean Data Assimilation for Coupled Models". Therefore, the description of the work done in this component can be found in the write-up on that project.

4. System development and integration. All ocean software components of COAMPS were incorporated into the COAMPS configuration management system. This includes programs for pre- and post-processing of ocean grids, bathymetry, and observations; the 3D multivariate optimum interpolation (MVOI) ocean analysis; and the Navy Coastal Ocean Model (NCOM). A general flux coupler was developed that allows for NCOM to use COAMPS atmospheric fields as the upper boundary condition.

RESULTS

1. Atmospheric reanalyses. The atmospheric reanalyses indicate that more accurate spatial and temporal variations are predicted by using the high-resolution fields used in this study, as opposed to results found with coarser grid models. Resolutions of 27 km and 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 demonstrate the ability to simulate pronounced coastal effects associated with flow around capes, bays, and inlets. Validation of these reanalyses against observational data is on-going in other projects.

2. Ocean model spin-up. We performed a one-year spin-up (October 1998 through September 1999) over the Mediterranean Sea in which NCOM was forced with the hourly fields from the COAMPS atmospheric reanalyses. NCOM used a horizontal resolution of 6 km with 40 vertical levels (15 sigma-levels at the top, 25 z-levels below). A flow of 1.0 Sv was prescribed at the Strait of Gibraltar. NCOM was able to simulate many observed features of the general circulation of the Mediterranean Sea, such as sub-basin scale gyres and intense coastal boundary currents. The features that were simulated include cyclonic motion over the northern part and anti-cyclonic motion over the southern part of the Mediterranean Sea. Two anticyclonic gyres were formed in the Alboran Sea with the eastern one constituting the Almeria-Oran front, which is a strong density gradient between the inflowing Atlantic water and the resident water of the Mediterranean. The prominent jet-like currents generated in the simulation include: the Algerian current flowing along the Algerian coast, the Atlantic Ionian Stream, the Mid-Mediterranean Jet, and the Asia minor current in the east. The simulation also includes cyclonic gyres (Lions, Tyrrhenian, Cretan, and Rhodes gyres) and the anticyclonic gyres (Pelops, Mersa-Matruh, and Shikmona gyres) that are consistent with observations made in the Mediterranean.

3. Ocean data assimilation. The results for this component of this project are included in the results section of the write-up on the project titled: "Ocean Data Assimilation for Coupled Models", reflecting the strong collaboration between these projects.

4. System development and integration. The development and testing of the flux coupler demonstrated the importance of not filtering the 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. It is also important to use the fluxes and stresses on the native grid of the atmospheric model.

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. The use of fully-coupled atmosphere-ocean prediction systems will not come without a price. The addition of a full-physics ocean model to the existing COAMPS atmospheric model approximately doubles the required memory and increases the total time to complete a given forecast by at least 15% (depending on the resolution of the ocean model). 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.

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 results and data that we generate as part of this program will be used by others. 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. Also, the addition of an ocean component of COAMPS could be included in our cooperative research with universities (e.g., University of Oklahoma) and other agencies (e.g., Lawrence Livermore National Laboratory, Central Intelligence Agency, Defense Threat Reduction Agency) that we currently support with the atmospheric component of COAMPS.

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