Ocean Data Assimilation for Coupled Models

Patricia A. Phoebus
Naval Research Laboratory
Monterey, CA 93943-5502
phone: (831) 656-4758 fax: (831) 656-4314 email: phoebus@nrlmry.navy.mil

Bob Rhodes
Naval Research Laboratory
Stennis Space Center, MS
phone: (228) 688-4704 fax: (228) 688-4759 email: rhodes@nrlssc.navy.mil
Award #: N00014WX30332

LONG-TERM GOALS

The long-term goal of this project is to improve our ability to analyze and predict the upper ocean/lower atmosphere environment, using sophisticated techniques that can exploit data from all available sources. This ability is fundamental to meeting DoD's needs for real-time analysis and improved air/sea simulation and prediction on a variety of scales, including mesoscale to tactical scale support in littoral environments and on the battlefield. To meet these needs, the Naval Research Laboratory is developing the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS), and has already transitioned the atmospheric prediction system component to operations.

OBJECTIVES

The objective of this particular project is to develop the globally-relocatable, three-dimensional multivariate ocean data analysis component of COAMPS, to provide a capability that will 1) provide the best possible initial conditions for the mesoscale ocean forecast model and 2) provide accurate lower boundary conditions for the atmospheric forecast model. The emphasis is on the development of a complete ocean data assimilation capability, where oceanographic data from a variety of sources are assimilated into an ocean forecast model at regular intervals in a dynamically consistent fashion. The ocean data analysis component must be able to analyze all conventionally available data sources, plus incorporate new data such as upper ocean velocity observations from drifter tracks and HF radar.

APPROACH

Plans for developing the next-generation ocean data assimilation system include leveraging the experience of both the atmospheric and oceanographic communities. Most current ocean analysis systems are based on the optimum interpolation (OI) methodology, which is a desirable statistical interpolation technique used successfully in meteorological systems for twenty years. However, the existing ocean analysis systems often use climatology as a background field, are univariate (in temperature) and two-dimensional, with vertical coupling of the various levels provided only through the use of stastistically derived synthetic profile observations. If such a system is used to initialize an ocean forecast model, additional steps must be taken to initialize the model's velocity field. Our project is expanding the univariate OI approach to a fully multivariate, three-dimensional OI ocean data assimilation capability (3D MVOI), where adjustments to the ocean's mass field will be correlated with

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **1998**	2. REPORT TYPE	3. DATES COVERED **00-00-1998 to 00-00-1998**
4. TITLE AND SUBTITLE **Ocean Data Assimilation for Coupled Models**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Research Laboratory,Monterey,CA,93943**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES **See also ADM002252.**		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**5**	

adjustments to the ocean's flow field, and a short-term model forecast will provide the analysis background field. This capability will set the stage for utilizing even more sophisticated techniques in the future, such as three-dimensional and four-dimensional variational data assimilation. A key ingredient of this research is to investigate how to properly specify the various statistical input parameters that determine the ultimate skill of the analysis. As we extend the analysis capability to assimilate multiple variable types from a number of different sources, new quality control techniques must be developed for those observations and the appropriate observation errors must be evaluated. We will progress from loose to tight coupling between the ocean and the atmospheric systems, and all development will ultimately be tested within the structure of the entire coupled prediction system. In addition, we will ensure that the software developed is fully compatible with other existing and planned components of COAMPS, thereby providing a seamless depiction of the air/sea environment within a single package. (Performers include Jim Cummings, NRL MRY, developer for 3D MVOI and Mike Carnes, NRL SSC, developer of synthetic profiles from SST and altimeter data.)

WORK COMPLETED

The first step in the development of the COAMPS Ocean Data Analysis (CODA) was to provide the capability to perform a sea-surface temperature (SST) analysis (using ship, buoy, AVHRR, and the new GOES data) and a sea-ice concentration analysis (using SSM/I data). This surface analysis can be performed on a number of different COAMPS grid projections at exactly the same grid locations as the atmospheric analysis. Furthermore, since COAMPS is executed on a nested grid structure, this ocean analysis is performed separately for each of the grid nests, thereby providing higher and higher resolution lower boundary conditions for the atmospheric model at whatever update cycle is specified. Options were provided to search for a suitable background field in a certain order--first from an ocean model forecast, next from the previous ocean analysis, and as a final default, from climatology.

Once the infrastructure for this two-dimensional surface analysis was fully incorporated as an integral part of the COAMPS software, further extensions of the ocean analysis component were completed within this same infrastructure, using some of the capabilities that had already been exercised in other Navy ocean analysis systems. The analysis was first extended vertically, so that temperature and salinity could be analyzed from the surface to the ocean bottom. However, rather than perform a series of two-dimensional analyses at depth, a vertical correlation function was added, which spreads the influence of each observation vertically as well as horizontally. A vertical correlation function also allows observations to be assimilated at observed depths; a preprocessing step of interpolating observations in the vertical, where the variation is very rapid, to the analysis levels is thus avoided. And to more fully optimize the analysis solution, the volume OI method was incorporated. The volume method, which has been used extensively in the meteorological community, computes the analysis solution for large overlapping volumes of grid points simultaneously, using all of the observations available in the volume. This method is not only a more mathematically optimal approach, but it is also far more efficient to execute on today's computers than methods that proceed grid point by grid point, selecting only a few observations to analyze at each point. The three-dimensional analysis assimilates altimeter sea surface height (SSH) data in the form of synthetic temperature and salinity profiles. The synthetic profiles are computed from analyzed SST and SSH predictor fields using climatological based regression models developed at NRL Stennis. The synthetic observations are appended to the real-time data and assimilated in the same way as any other observation, but with unique error characteristics specified. Sophisticated quality control procedures have been developed for all these data sources.

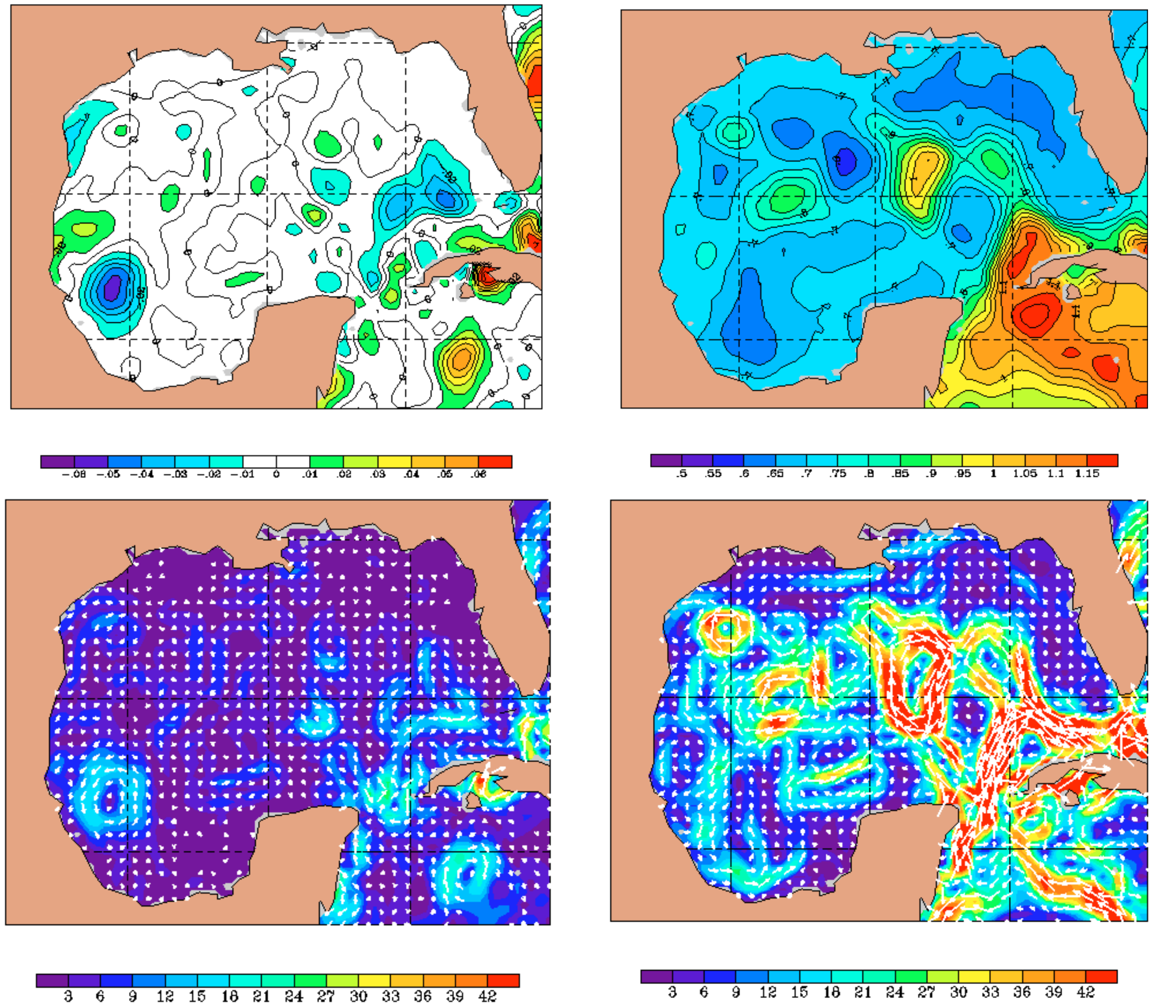
The most recent capability developed for CODA is also the most unique. We are now able to perform a true three-dimensional multivariate optimum interpolation (3D MVOI) analysis on the COAMPS nested grid projections. The correlated multivariate analysis variables in CODA are geopotential and the u-v velocity components. The mathematical form of the multivariate correlation functions are identical to those used in the COAMPS atmospheric analysis, but are parameterized to represent oceanographic length scales and background errors. In addition, temperature and salinity observations are analyzed simultaneously with geopotential and velocity as uncorrelated scalar variables, much as moisture is analyzed in the atmospheric system. This new capability sets the stage for performing some interesting experiments in ocean model initialization, working towards the goal of having an ocean data assimilation system fully capable of executing in an incremental update cycle mode, as has been done in the atmosphere for years. This capability is a necessary step if we are going to be able to run fully coupled air/ocean prediction systems in real-time.

RESULTS

The version of COAMPS that includes the CODA nested-grid ocean surface analysis has been utilized for several interesting case studies. In a particularly high-profile case, NRL participated in several historical re-analyses of mesoscale atmospheric conditions during the Gulf War. These re-analyses were used to provide the meteorological parameter input for transport and dispersion models as part of the Gulf War Illness studies, which attempted to identify potential areas of troop exposure to chemical agents unknowingly released during ammunition demolitions in Iraq. These experiments demonstrated the importance of grid compatibility between the ocean and atmospheric analyses. Cases that utilized CODA to re-analyze historical ocean conditions demonstrated that this grid compatibility was essential for providing the best high-resolution estimates of the surface fluxes. When ocean temperatures were obtained from other sources, it was possible to get an air-land temperature difference where there should have been an air-sea temperature difference, or vice versa.

CODA was also used in a study of precipitation from landfalling storms along the California Coast during this past El Nino-enhanced winter storm season. COAMPS forecasts produced using real-time CODA SST analyses showed significant differences in amount and patterns of precipitation than those produced using climatological SST data. The more accurate results depicted from the CODA analysis demonstrated that a difference of only a few degrees in the SST could significantly impact the outcome of the high-resolution atmospheric forecasts.

CODA 3D MVOI analyses have been successfully executed in each of the four COAMPS geographic domains run operationally at FNMOC. These areas include the Sea of Japan, Mediterranean Sea, Arabian Sea, and a new region centered over Mexico and Central America. No problems have been encountered cycling CODA using the previous analysis as a background field, and the analyzed fields are consistent with known oceanographic circulation patterns in each of the geographic domains. An example of a multivariate analysis is illustrated in the following figures. A 22-km Mercator grid was defined for the Gulf of Mexico and a 3D MVOI analysis was started from climatology on 10 April 1998 and run for three days using a 24-hour update cycle. Figure 1a (upper left) shows the analyzed geopotential increment at the surface and Figure 1b (upper right) shows the



updated surface geopotential field relative to 800 m. A well developed Loop Current and several warm-core Loop Current eddies are present. Figure 1c (lower left) shows the velocity increments, and Figure 1d (lower right) shows the updated surface velocity field. The strong constraints of full geostrophic coupling and nondivergence were assumed in the computation of the geopotential/velocity multivariate correlations in this example. However, the formulation of the MVOI in CODA allows for the constraints to be relaxed and to vary spatially.

IMPACT/APPLICATIONS

Multivariate analysis of mass and velocity in the ocean is new. In an ocean MVOI analysis, mass and velocity are consistent with simple linear dynamic constraints, and the constraints are built right into the algorithm. It is likely that a cold-start initialization of an ocean forecast model is enhanced from such completely specified, dynamically consistent, background fields. Long spin-up runs of a regional ocean model thus may not be necessary, thereby allowing the ocean modeling and assimilation components of

COAMPS to be easily and quickly re-located in a time of crisis, similar to what is now possible for the atmospheric components of COAMPS.

TRANSITIONS

The CODA surface analysis has been transitioned via a 6.4 project sponsored by the Oceanographer of the Navy and is now operational as part of the COAMPS atmospheric prediction system. That system is executed at Fleet Numerical Meteorology and Oceanography Center for several regional areas around the globe. This same version of COAMPS comprises the Tactical Atmospheric Mesoscale System/Real-Time, which is currently being run on-scene in demonstration mode at the San Diego METOC center, as well as by several other defense-related customers. The CODA 3D MVOI is installed in the COAMPS developmental software configuration management system at NRL Monterey. As such, all developmental users of COAMPS routinely utilize CODA. These users include the Navy Laboratories, the National Laboratories, and several universities.

RELATED PROJECTS

This project complements: 1) several ongoing efforts at NRL Monterey focusing on atmospheric mescoscale modeling, data assimilation, and air/sea interaction, 2) the ongoing ocean modeling and data assimilation efforts at NRL Stennis, and 3) the joint NRL (SSC/MRY) Navy Coastal Ocean Model (NCOM) development effort, which directly supports the ocean forecast component of COAMPS.

PUBLICATIONS

Chang, S.W., D.L. Westphal, T.R. Holt, N.L. Baker, T.F. Hogan, L.R. Brody, R.A. Godfrey, J.S. Goerss, J.A. Cummings, D.J. Laws, D.W. Hines (1999). Meteorological re-analysis for the study of Gulf War Illnesses: Khamisiyah Case Study. To appear, *Weather and Forecasting*.