U.S. GODAE: GLOBAL OCEAN PREDICTION WITH THE HYBRID COORDINATE OCEAN MODEL (HYCOM)

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NOAA Grant Number: NA17RJ1226
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LONG-TERM GOALS

A broad partnership of institutions is collaborating in developing and demonstrating the performance and application of eddy-resolving, real-time global and basin-scale ocean prediction systems using the HYbrid Coordinate Ocean Model (HYCOM). These systems will be transitioned for operational use by the U.S. Navy at both the Naval Oceanographic Office (NAVOCEANO), Stennis Space Center, MS, and the Fleet Numerical Meteorology and Oceanography Center (FNMOC), Monterey, CA, and by NOAA at the National Centers for Environmental Prediction (NCEP), Washington, D.C. The systems will run efficiently on a variety of massively parallel computers and will include sophisticated, but relatively inexpensive, data assimilation techniques for assimilation of satellite altimeter sea surface height (SSH) and sea surface temperature (SST) as well as in-situ temperature, salinity, and float displacement.

The Partnership under this proposal represents a truly broad spectrum of the oceanographic community, bringing together academia, federal agencies, and industry/commercial entities, spanning modeling, data assimilation, data management and serving, observational capabilities, and application of HYCOM prediction system outputs. The institutions participating in this Partnership have long histories of supporting and carrying out a wide range of oceanographic and ocean prediction-related research and data management. All institutions are committed to validating an operational hybrid-coordinate ocean model that combines the strengths of the vertical coordinates used in the present generation of ocean models by placing them where they perform best. This collaborative Partnership provides an opportunity to leverage and accelerate the efforts of existing and planned projects, in order to produce a higher quality product that will collectively better serve a wider range of users than would the individual projects. In addition to operational eddy-resolving global and basin-scale ocean prediction systems for the U.S. Navy and NOAA, respectively, this project offers an outstanding opportunity for NOAA-Navy collaboration and cooperation ranging from research to the operational level.

This effort is part of a 5-year (FY04-08) multi-institutional National Ocean Partnership Program (NOPP) project which includes the **U. of Miami** (E. Chassignet, G. Halliwell, M. Iskandarani, T. Chin, A. Mariano, D. Bi, Z. Garraffo, A. Srinivasan, P. Minnett, R. Evans), **NRL/STENNIS** (H. Hurlburt, A. Wallcraft, J. Metzger, B. Kara, J. Cummings, G. Jacobs, H. Ngodock, L. Parent, C.A. Blain, P. Hogan, J. Kindle), **NAVOCEANO** (E. Johnson, J. Harding), **FNMOC** (M. Clancy), **NRL/MONTEREY** (R. Hodur, M. Flatau, X. Hong, J. Pullen), **NOAA/NCEP/MMAB** (D.B. Rao,

C. Lozano), **NOAA/NOS** (F. Aikman), **NOAA/AOML** (C. Thacker), **NOAA/PMEL** (S. Hankin), **Planning System Inc.** (O.M. Smedstad, B. Lunde), **LANL** (R. Bleck), **SHOM** (R. Baraille), **LEGI** (P. Brasseur), **OPeNDAP** (P. Cornillon), **U. of S. Mississippi** (W. Schmitz), **U. of N. Carolina** (C. Werner), **Rutgers** (J. Wilkin, D. Haidvogel), **U. of S. Florida** (R. Weisberg), **Fugro-GEOS/Ocean Numerics** (D. Szabo, G. Evensen), **Horizon Marine Inc.** (J. Feeney, S. Anderson), **ROFFS** (M. Roffer), **Orbimage** (L. Stathoplos), **Shell Oil Company** (M. Vogel), **ExxonMobil** (O. Esenkov).

OBJECTIVES

The Partnership is addressing the Global Ocean Data Assimilation Experiment (GODAE) objectives of three-dimensional (3D) depiction of the ocean state at fine resolution in real-time and provision of boundary conditions for coastal and regional models. It will also provide the ocean component and oceanic boundary conditions for a global coupled ocean-atmosphere prediction model. It will make these results available to the GODAE modeling community and general users on a 24/7 operational basis via a comprehensive data management strategy.

APPROACH AND WORK PLAN

HYCOM development is the result of collaborative efforts among the University of Miami, the Naval Research Laboratory (NRL), and the Los Alamos National Laboratory (LANL), as part of the multi-institutional HYCOM Consortium for Data-Assimilative Ocean Modeling. This effort was funded by the National Ocean Partnership Program (NOPP) in 1999 to develop and evaluate a data-assimilative hybrid isopycnal-sigma-pressure (generalized) coordinate ocean model (Bleck, 2002; Chassignet et al., 2003; Halliwell, 2003). HYCOM has been configured globally, on basin scales, and regionally. The fully global configuration is currently being integrated with ~60 km mid-latitude resolution. Coupling to the Los Alamos ice model (CICE) is underway. North Pacific and Atlantic basin-scale simulations have been integrated with ~7 km mid-latitude resolution, our target resolution for the global configuration. More details of these free-running simulations can be found at http://hycom.rsmas.miami.edu.

While HYCOM is a highly sophisticated model, including a large suite of physical processes and incorporating numerical techniques that are optimal for dynamically different regions of the ocean, data assimilation is still essential a) because many ocean phenomena are due to flow instabilities and thus are not a deterministic response to atmospheric forcing, b) because of errors in the atmospheric forcing, and c) because of ocean model imperfections, including limitations in resolution. One large body of data is obtained remotely from instruments aboard satellites. They provide substantial information about the ocean's space-time variability at the surface, but they are insufficient by themselves for specifying the subsurface variability. Another significant body of data is in the form of vertical profiles from XBTs, CTDs, and profiling floats *(e.g.,* ARGO). While these are too sparse to characterize the horizontal variability, they provide valuable information about the vertical stratification. Even together, they are insufficient to determine the state of the ocean completely, so it is necessary to exploit prior knowledge in the form of statistics determined from past observations as well as our understanding of ocean dynamics. Our intent is to combine all sources of information synergistically to produce the best possible depiction of the evolving ocean.

Several techniques for assimilating data into HYCOM are either in place or under development. These techniques vary in sophistication and computational requirements and include: Optimum

Interpolation (OI/Cooper-Haines) (PSI, O.M. Smedstad; SHOM, R. Baraille), MVOI/3D-VAR (NRL, J. Cummings; NOAA/NCEP, C. Lozano), SEEK filter (Sverdrup Inc., L. Parent; LEGI, P. Brasseur), Reduced Order Information Filter (ROIF) (U. of Miami, T. Chin, A. Mariano; NOAA/AOML, C. Thacker), Ensemble Kalman Filter (EnKF) (Ocean Numerics, G. Evensen), Reduced Order Adaptive Filter (ROAF) (including adjoint) (SHOM, R. Baraille), and the 4D-VAR Representer Method (USM, H. Ngodock; NRL, G. Jacobs). All of these techniques are available for this project and all developers are part of this Partnership.

WORK COMPLETED

a) Global, basin-scale, and regional simulations
b) Implementation of data assimilation capabilities for HYCOM
c) Evaluation of the ability of the North Atlantic ocean prediction system to provide boundary conditions to coastal models
d) Model outputs available via a Live Access Server

RESULTS

This NOPP was funded in FY04 and builds on the results of a previous NOPP effort to develop and evaluate a data-assimilative hybrid isopycnal-sigma-pressure (generalized) coordinate ocean model, i.e. HYCOM (see separate annual report on the "HYCOM Consortium for Data Assimilative Ocean Modeling"). Here we mostly report on the evaluation of the $1/12^{o}$ HYCOM Atlantic domain which is a major component of our effort since the ultimate goal is a transition to a $1/12^{o}$ global ocean prediction system in 2006. The data assimilative 1/12° Atlantic version of HYCOM has been running since the fall of 2002. The system assimilates the daily MODAS SSH anomaly analysis and SST of available real time satellite data. The atmospheric forcing of the near real time system comes from the Fleet Numerical Meteorology and Oceanography Center (FNMOC) Navy Operational Global Atmospheric Prediction System (NOGAPS). The results can be seen at http://hycom.rsmas.miami.edu.

A comparison of four data assimilative ocean models used by the Navy to SeaWiFS ocean color has been performed in the Gulf of Mexico. The ocean models are the 1/12° Atlantic HYCOM (~8 km resolution in the Gulf of Mexico), the 1/24° Intra-Americas Sea (IAS) NCOM (6 km resolution), the 1/16° global NLOM (8 km resolution), and the 1/32° global NLOM (4 km resolution). They are compared to ocean color from SeaWiFS in the Gulf of Mexico (2 June 2003-29 Sept. 2003). All assimilate the operational 1/8° MODAS sea surface temperature analyses of AVHRR data and satellite altimeter sea surface height (SSH). GFO (through 5 Sept.) and JASON-1 altimeter data were used. The NLOM systems assimilate altimeter track data using the model forecast as a first guess. The altimeter data is projected downward using EOF regression (Hurlburt et al., 1990) based on model statistics. The HYCOM and IAS NCOM systems assimilate the operational 1/4° MODAS SSH analyses which are model independent. HYCOM projects SSH downward using the technique of Cooper and Haines (1996) and the NCOM systems assimilate synthetic temperature and salinity profiles based on SSH, SST and statistics of the historical hydrographic data base. All use atmospheric forcing from the Fleet Numerical Meteorology and Oceanography Center (FNMOC) Navy Operational Global Atmospheric Prediction System (NOGAPS).

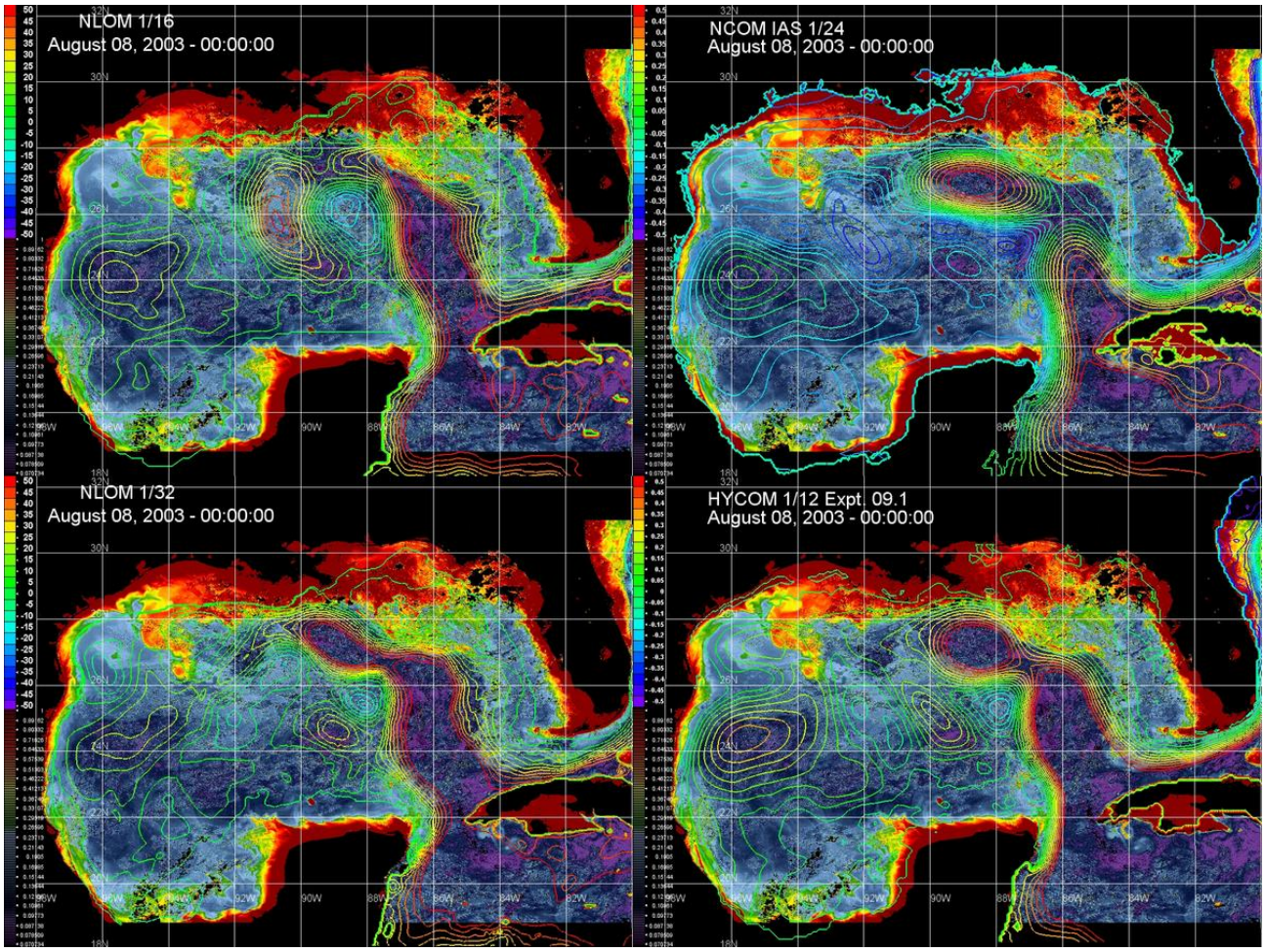

Figure 1. Model SSH contours overlain on SeaWiFS imagery. The SeaWiFS imagery is a composite of the most recent cloud free pixel over the preceding 6 days.

The results are presented in Figure 1 in four panel images with model SSH contours overlain on SeaWiFS imagery. Both bright and dark areas of ocean color are very informative. Both the Loop Current and shed eddies show up clearly as especially dark areas of low chlorophyll. When the model matches well, the dark area is pretty well hidden, but mismatches show up clearly and the 4-way comparison is very effective in bringing this out. The bright areas of high chlorophyll tend to be advected into plumes by strong currents but sometimes also occur in the center of cyclonic (counterclockwise) eddies. The SSH contours are colored prismatically from low (violet) to high (red). Cyclonic eddies are relative lows and anticyclonic are relative highs.

A strong component of our HYCOM initiative is web outreach. A critical problem in ocean modeling and data assimilation is making both the observational data and model output available to (a) the members of our consortium for HYCOM and data assimilation code development, (b) the wider oceanographic and scientific communities, including climate and ocean ecosystem researchers; and (c) the general public (especially students in elementary and high school). The real-time global and basin model outputs will be made available to the community at large within 24 hours via the U.S GODAE and Miami Live Access Servers (LAS). Software development and

integration of the server system will be performed by the NOAA/PMEL group (S. Hankin) in collaboration with those in charge of the U.S. GODAE and Miami servers. Collaboration with the OPeNDAP (formerly named DODS) group (URI, P. Cornillon) will ensure that the remote data sets and model outputs are accessible in real time, despite their size. OPeNDAP is vital in this regard when dealing with huge data sets (e.g., 7 km grid global 3D), because of its built-in ability to perform subsetting. Only the subset of data required for the user-requested product in his/her selected region need be sent over the network (*e.g.*, Gulf of Mexico SST on a particular date). The Live Access Servers are a highly configurable Web server designed to provide flexible access to geo-referenced scientific data. It enables the Web user to visualize data with on-the-fly graphics, request custom subsets of variables in a choice of file formats, access background reference material about the data (metadata), and compare (difference) variables from distributed locations. A. Mariano is putting together a Web-based reference site on ocean currents (Mariano et al., 2002) (accessible at http://oceancurrents.rsmas.miami.edu).

IMPACT/APPLICATIONS

Three-dimensional (3D) depiction of the ocean state at fine resolution in real-time and provision of boundary conditions for coastal and regional models in the context of the Global Ocean Data Assimilation Experiment (GODAE).

National Security

Generation of optimal estimates of the time-varying ocean state in support of U.S. Navy's needs on synoptic time scales on the order of weeks to months and on spatial scales typically on the order of 10-1000 km (mesoscale).

Economic Development

Precise knowledge and prediction of ocean mesoscale features is used by the oil industry and fisheries for an optimal use of their resources.

Science Education and Communication

Web-access to an up-to-date description of the world ocean currents.

TRANSITIONS

None.

RELATED PROJECTS

HYCOM Consortium for Data Assimilative Ocean Modeling

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