HYCOM CONSORTIUM FOR DATA ASSIMILATIVE OCEAN MODELING

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Award Number: N00014-99-1-1066
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LONG-TERM GOALS

Development of a consortium for hybrid-coordinate data assimilative ocean modeling to make HYCOM (HYbrid Coordinate Ocean Model) a state of the art community ocean model with data assimilation capability that can (1) be used in a wide range of ocean-related research, (2) be used in a next generation eddy-resolving global ocean prediction system and (3) be coupled to a variety of other models, including littoral, atmospheric, ice and bio-chemical.

This effort is part of a 5-year (FY00-04) multi-institutional National Ocean Partnership Program (NOPP) project which includes E. Chassignet (coordinator), G. Halliwell, and A. Mariano (U. of Miami/RSMAS), M. Chin (JPL/U. of Miami), R. Bleck (LANL), H. Hurlburt, A. Wallcraft, P. Hogan, R. Rhodes, C. Barron, and G. Jacobs (NRL-Stennis), O.M. Smedstad (Planning Systems, Inc.), W.C. Thacker (NOAA/AOML), and R. Baraille (SHOM).

OBJECTIVES

The primary objective is the establishment of a global real-time ocean forecast system based on a hybrid-coordinate ocean model with sophisticated data assimilation techniques that can be efficiently executed on massively parallel computers. The secondary objectives are a) to evaluate the model's performance in reproducing the oceanic circulation, with a special focus on the coastal regions; b) to refine the hybrid coordinate design of the ocean model, especially in shallow coastal regions, and c) to evaluate the model's forecast skills and usefulness in providing boundary conditions for ultra fine-mesh coastal models.

APPROACH AND WORK PLAN

A series of numerical models of increasing complexity and resolution is used to (a) evaluate the hybrid coordinate design of the model, (b) develop an understanding of the interaction between the ocean interior and the coastal regions, and (c) evaluate the model's forecast skills.

WORK COMPLETED

a) Model development: Release of HYCOM 2.1
b) Global, basin-scale, and regional simulations
c) Inclusion and evaluation of four vertical mixing schemes (Halliwell, 2004)
d) Development and testing of advection schemes

e) Evaluation of the hybrid coordinate (Chassignet et al., 2003)
f) Data assimilation capabilities for HYCOM
g) Evaluation of the ability of the North Atlantic ocean prediction system to provide boundary conditions to coastal models

RESULTS

Traditional vertical coordinate choices [z-level, terrain-following (sigma), isopycnic] are not by themselves optimal everywhere in the ocean, as pointed out by recent model comparison exercises performed in Europe (DYnamics of North Atlantic MOdels - DYNAMO) and in the U.S. (Data Assimilation and Model Evaluation Experiment - DAMEE). Ideally, an ocean general circulation model (OGCM) should (a) retain its water mass characteristics for centuries (a characteristic of isopycnic coordinates), (b) have high vertical resolution in the surface mixed layer (a characteristic of z-level coordinates) for proper representation of thermodynamical and biochemical processes, (c) maintain sufficient vertical resolution in unstratified or weakly-stratified regions of the ocean, and (d) have high vertical resolution in coastal regions (a characteristic of terrain-following coordinates).

The hybrid coordinate adopted in HYCOM (HYbrid Coordinate Ocean Model) is one that is isopycnal in the open, stratified ocean, but smoothly reverts to a terrain-following coordinate in shallow coastal regions, and to pressure-level coordinates in the mixed layer and/or unstratified seas. The hybrid coordinate extends the geographic range of applicability of traditional isopycnic coordinate circulation models (the basis of the present hybrid code), such as the Miami Isopycnic Coordinate Ocean Model (MICOM) and the Navy Layered Ocean Model (NLOM), toward shallow coastal seas and unstratified parts of the world ocean [see Bleck (2002) for details].

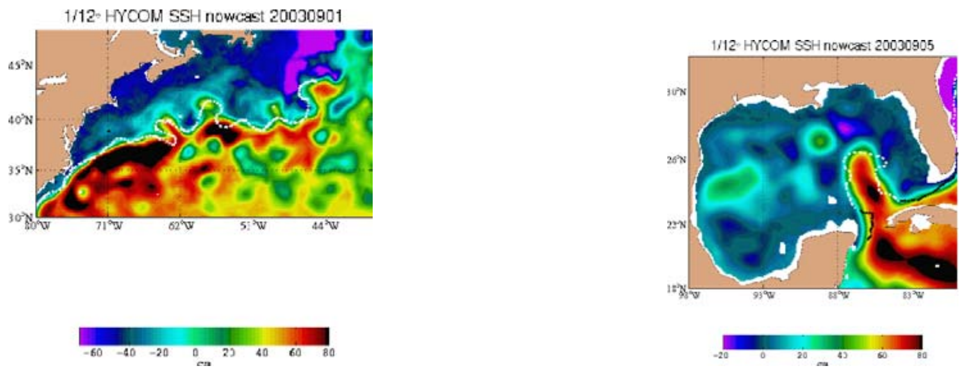
The latest version of HYCOM (version 2.1) was released in 2002 and is the result of collaborative efforts between the Naval Research Laboratory (Wallcraft), the University of Miami (Halliwell), and the Los Alamos National Laboratory (Bleck). A major aspect of this new release is that the standard version of HYCOM is now ready for application as a fully global ocean model: Halos were added for MPI to automatically support periodic boundaries and the capability to handle orthogonal curvilinear grids was added and used to create a bi-polar (PanAm) grid to cover the northern polar region. The latter matches the spherical grid covering the remainder of the global ocean at 47°N. Other additions to HYCOM 2.1 include support for nested-domain open boundaries, Mellor-Yamada 2.5 (Mellor and Yamada, 1982) and Price-Weller-Pinkel (Price et al., 1986) as new embedded mixed layer options, support for multiple tracers, and NetCDF output files (see http://hycom.rsmas.miami.edu for details).

The capability of assigning additional coordinate surfaces to the oceanic mixed layer in HYCOM gives us the option of implementing sophisticated vertical mixing turbulence closure schemes. Halliwell (2003) evaluated the vertical mixing algorithms embedded in HYCOM using low-resolution climatological simulations of the Atlantic Ocean. Thirteen model experiments were analyzed involving different combinations of vertical mixing algorithms, vertical coordinate choice, and vertical resolution. The full set of vertical mixing options contained in the latest version of HYCOM 2.1 includes six primary vertical mixing algorithms, of which two are non-slab models and four are slab models. The two non-slab models govern vertical mixing throughout the water column and are the nonlocal K-Profile Parameterization model of Large et al. (1994) (KPP), and the level 2.5 turbulence closure algorithm of Mellor and Yamada (1982) (MY). The slab models include the dynamical instability model of Price et al. (1986) (PWP) and three versions of the Kraus-Turner model.

HYCOM 2.1 has been configured globally, on basin scales, and regionally. The fully global configuration (present resolution of .72 ^{o}) is currently being integrated by J. Metzger (NRL). Coupling of the fully global configuration (resolution of 2 ^{o}) to an atmospheric model has been performed by R. Bleck (Los Alamos) and S. Sun (NASA/GISS). Coupling to an ice model is underway and is being evaluated by D. Bi (RSMAS). The North Pacific basin-scale simulations are based on simulations previously performed with NLOM (Metzger, Hurlburt). The North Atlantic basin-scale simulations are based on the Community Modeling Experiment (CME), DYNAMO, and MICOM experiences (1^{o}, $1/3^{o}$, and $1/12^{o}$ grid spacing, respectively).

The series of North Atlantic CME-like experiments investigates the impact of the vertical coordinate choice and resolution, reference density, and thermobaricity. In Chassignet et al. (2003), the hybrid model's performance is evaluated by comparison to observations and to previous simulations configured for the North and Equatorial Atlantic. Building on past studies with the Community Modeling Experiment (CME) configuration (Chassignet et al., 1996; Smith et al., 2000), we examined the effect of the coordinate choice(s) on the model's ability to accurately represent the water mass distributions and three-dimensional circulation of the Atlantic. We performed several single-coordinate experiments, not only to illustrate the flexibility of the model, but also to bring forth some of the limitations associated with such a choice. We also addressed one specific issue which is present in models such as HYCOM that employ potential density either as the sole vertical coordinate or as one component of the hybrid framework: the question of how best to represent the potential density distribution throughout the entire oceanic depth range for a given reference pressure. The series of experiments demonstrated that a reference pressure at 2000 dbar indeed allow for a correct representation of the dense water masses that originate in Antarctica. When a reference pressure at the surface is used (sigma-theta), these water masses are characterized by an inversion in the vertical potential density profile which cannot be modeled. The addition of thermobaricity allowed us to quantify its importance on the surface and deep ocean circulations.

The $1/12^{o}$ HYCOM Atlantic domain is a major component of our HYCOM 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 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 current assimilation system is computationally very efficient. It increases the run time of the model by only a few percent compared to the model run without assimilation. Examples of the results from the 1/12° Atlantic model can be seen in figure 1a and b. The figures show the model SSH for the Gulf Stream region on 15 September 2003, figure 4a, and the Gulf of Mexico region on 5 September 2003, figure 4b. Overlain on the SSH is an independent frontal analysis of SST data performed at NAVOCEANO. The agreement between the model and the independent observations is good. The results can be seen at http://hycom.rsmas.miami.edu.



(a) **(b)**

Figure 1. (a) The sea surface height from the 1/12° Atlantic HYCOM in the Gulf Stream region on 15 September 2003 and (b) the sea surface height in the Gulf of Mexico region on 5 September 2003. Overlain is an independent frontal analysis of SST observation performed at NAVOCEANO. The frontal position is marked in black if the observations are more than 2 days old.

For assimilation of surface altimetry data, the consortium is evaluating the Optimal Interpolation (OI) scheme combined with a Cooper-Haines vertical projection of the surface information (presently in place in the North Atlantic ocean prediction system), the Single Evolutive Extended Kalman (SEEK) filter, and the Reduced Order Information Filter (ROIF).

In order to evaluate the model's forecast skills and usefulness in providing boundary conditions for ultra fine-mesh coastal models, G. Halliwell has performed preliminary West Florida Shelf simulations. A 1/12-degree model domain was nested within the Atlantic basin simulations of O. M. Smedstad that used SSH assimilation, and was forced by the same 3-hourly FNMOC fields (with wind stress adjusted to the ECMWF mean) that is used in the North Atlantic Ocean prediction system. Initial experiments were run over a two-month time interval and presented at the HYCOM meeting in August 2003. Overall, the performance of the nested model was quite good. This initial West Florida Shelf analysis has also been designed as a sensitivity study to (1) nesting procedure, (2) vertical mixing choice, and (3) vertical coordinate choice. In particular, the latter evaluation will compare cases where vertical coordinates are purely sigma over the shelf and upper slope versus being predominantly *p* and isopycnic coordinates.

Finally, 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). For that purpose, a Live Access Server (LAS) has been installed in Miami. LAS was developed a group of scientists at NOAA-PMEL and is 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. Srinivasan (U. of Miami) is in charge of maintaining the server. 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

The generalized vertical coordinate in HYCOM is designed to make optimal use of three types of vertical coordinate, isopycnal, σ and z-level, although it is not limited to these types. Isopycnals are the natural coordinate in stratified deep water, terrain-following (σ) coordinates in shallow water and z-levels in the mixed layer. The layered continuity equation allows a dynamical space and time varying transition between the three coordinate types. HYCOM also permits isopycnals intersecting sloping topography by allowing zero thickness layers. Therefore, it does allow accurate transition between deep and shallow water, historically a very difficult problem for ocean models. It also allows high vertical resolution where it is most needed, over the shelf and in the mixed layer. The isopycnal coordinate reduces the need for high vertical resolution in deep water. HYCOM is a recent and promising design for next generation global and regional ocean prediction systems and it extends the range of application for ocean models in research.

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

U.S. GODAE: Global Ocean Prediction with the HYbrid Coordinate Ocean Model

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