Global HYCOM and Advanced Data Assimilation

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LONG-TERM GOALS

The long-term goal is to use a HYbrid Coordinate Ocean Model (HYCOM) with data assimilation in an eddy-resolving, ully global ocean prediction system with transition to the Naval Oceanographic Office (NAVOCEANO) at .08° equatorial resolution in 2006 and with .04° resolution by the end of the decade. Equatorial resolution of .08° (.04°) increases from 9 km (4.4 km) at the equator to 6 km (3 km) at 47° latitude. A bipolar "PanAm" grid covers the Arctic. At 47°N it matches the spherical grid covering the rest of the global ocean. The model will include shallow water to a minimum depth of 10-20 m and will provide boundary conditions to finer resolution coastal models that may use HYCOM or a different ocean model.

OBJECTIVES

Exploratory development and evaluation of HYCOM as a data-assimilative next generation model with generalized coordinates (hybrid isopycnal/terrain-following (σ)/z) and application of this model to eddy-resolving global ocean prediction. First use the Pacific north of 20°S, the Japan/East Sea (JES) and the Intra-Americas Sea (IAS) as test beds for modeling, grid nesting and/or a hierarchy of data assimilation schemes from relatively simple to advanced.

APPROACH

This project is highly collaborative with several other projects (see Related Projects). These projects focus on other aspects of the research such as ocean dynamics, most aspects of model development, other model domains and other data assimilation techniques. This project focuses on development and evaluation of Pacific HYCOM north of 20°S, and in high resolution sub-domains, nesting and advanced data assimilation. The Pacific modeling is in preparation for .08° global HYCOM beginning in FY04.

HYCOM is designed as a generalized (hybrid isopycnal/σ/z) coordinate ocean model. It is isopycnal in the open stratified ocean, but reverts to a terrain-following coordinate in shallow coastal regions, and to z-level coordinates near the surface in the mixed layer. This generalized vertical coordinate approach is dynamic in space and time via the layered continuity equation, which allows a dynamical transition between the coordinate types. Like MICOM, HYCOM permits isopycnals intersecting sloping topography by allowing zero thickness layers. HYCOM was developed from MICOM using the theoretical foundation for implementing a hybrid coordinate system set forth in Bleck and Boudra (1981) and Bleck and Benjamin (1993).

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14. ABSTRACT
The long-term goal is to use a HYbrid Coordinate Ocean Model (HYCOM) with data assimilation in an eddy-resolving, ully global ocean prediction system with transition to the Naval Oceanographic Office (NAVOCEANO) at .08?? equatorial resolution in 2006 and with .04?? resolution by the end of the decade. Equatorial resolution of .08?? (.04??) increases from 9 km (4.4 km) at the equator to 6 km (3 km) at 47?? latitude. A bipolar ???PanAm??? grid covers the Arctic. At 47??N it matches the spherical grid covering the rest of the global ocean. The model will include shallow water to a minimum depth of 10-20 m and will provide boundary conditions to finer resolution coastal models that may use HYCOM or a different ocean model.

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HYCOM development is a close collaboration between Los Alamos National Laboratory (Rainer Bleck), NRL (Alan Wallcraft) and the University of Miami (George Halliwell), where the person in parenthesis is the lead performer in each group. Alan Wallcraft is in charge of developing and maintaining the standard version of the model; one that is scalable and portable and can run on the latest computer architectures. The HYCOM/NOPP project has the lead on basic model development and a Common HPC Software Support Initiative (CHSSI) project has the lead on scalability and portability of the computer code. Model grid nesting (in collaboration with U. Miami) is the main contribution of this project to model development. HYCOM will be maintained as a single source code with maximum feasible backward compatibility. The source code and documentation will be developed to the standard for a Navy operational product and for a community ocean model.

Initially, NRL work on the global domain will be at relatively coarse resolution (.72° then .24° at the equator) under the HYCOM/NOPP project in close collaboration with Rainer Bleck (LANL) and Eric Chassignet (U. Miami). This project will begin a major role in FY04 when the global model becomes eddy resolving with an increase to .08° equatorial (~7 km mid-latitude) resolution. During FY01-FY04 this project will work on development and evaluation of a HYCOM Pacific model with up to .08° equatorial resolution with Joe Metzger (NRL) taking the lead. The .08° HYCOM Pacific modeling will use computer time from a FY02-04 DoD High Performance Computing (HPC) Challenge grant (Eric Chassignet lead PI). A comparable effort is underway for the Atlantic as part of the HYCOM/NOPP project (see separate ONR reports).

The IAS domain circumscribes the Caribbean, Gulf of Mexico and Bahamas region. Tamara Townsend (NRL) has the lead on IAS modeling which is included (1) for the nesting effort, (2) for the opportunity to perform numerous simulations at .08° resolution, even a few at .04°, and (3) as a high resolution test bed for advanced data assimilation techniques. The HYCOM JES modeling is primarily the domain of other related projects. It is included here only as needed to support the data assimilation effort. The JES is smaller than the IAS and has a distinctly different mid-latitude dynamical regime (Hogan and Hurlburt, 2000) that is more relevant to the Gulf Stream (Hurlburt and Hogan, 2000) and the Kuroshio (Hurlburt et al., 1996) and is thus an excellent high resolution test bed for advanced data assimilation. Pat Hogan (NRL) is the JES modeler for this project.

The main participants in the project data assimilation effort are Gregg Jacobs (NRL), Hans Ngodock (associate researcher at U. Southern Mississippi and former postdoc of Andrew Bennett) and Ole Martin Smedstad (PSI). The main non-project collaborators are Remy Baraille (SHOM contractor in France), Geir Evensen (Nansen Center in Norway) and Carlisle Thacker (NOAA/AOML). Ole Martin Smedstad will take the lead in implementing baseline data assimilation techniques. The baseline techniques will be used in comparison to more advanced techniques for efficiency and accuracy. Gregg Jacobs and Hans Ngodock plan to work on HYCOM data assimilation using (1) the 4DVAR representer method with an adjoint to be provided by Remy Baraille and (2) ensemble Kalman filtering, the latter in collaboration with Geir Evensen. Complete altimeter data sets from TOPEX/POSEIDON, ERS-2, GFO, JASON-1, and ENVISAT with additional corrections will be available up to real time; similarly for MCSSTs. In addition, 1/8° mesoscale depicting MODAS analyses of sea surface height (SSH) and sea surface temperature (SST) with estimated error fields will be available. The data assimilative model results will be compared with unassimilated data enumerated in the HYCOM/NOPP ONR report. Both sets will be used in model evaluation.

WORK COMPLETED

Under collaborative HYCOM projects, Alan Wallcraft completed development of HYCOM 2.1 that includes support for orthogonal curvilinear grids (required for global modeling), off-line one-way nesting (the contribution of this project), two additional mixed layer formulations (added by George Halliwell) and other enhancements. It was released for general use in September 2002.

In the past year, HYCOM has been used to model the Pacific Ocean north of 20°S, including the marginal seas, at 0.16° and 0.08° equatorial resolutions. These translate to ~14 km and ~7 km mid-latitude resolutions, respectively. Seven 0.16° experiments were performed testing a) the horizontal diffusion parameter space and b) model sensitivity to atmospheric forcing. Two simulations were performed at 0.08° resolution, one forced with climatological ECMWF winds (8.5 model years) and the other under a FY02-04 HPC Challenge project using Hellerman and Rosenstein (HR) (1983) winds (9.5 model years). The 0.08° model was also integrated using interannual FNMOC winds and thermal forcing from January 2001-May 2002, a period that spanned the life cycle of Hurricane Juliette.

Development of global HYCOM began at 2.0° and 0.72° equatorial resolutions. The 2.0° model was used mostly as a test bed for model code development. An initial 0.72° model simulation has been run for 5.5 years with ECMWF high frequency climatological forcing.

Continued development, testing and evaluation of a one-way nesting capability is underway using the .08º IAS HYCOM with boundary conditions from an enclosing coarser resolution Atlantic HYCOM run by the HYCOM/NOPP project. A four year .08º nested IAS HYCOM simulation was completed and analysis of the results performed by Tammy Townsend. Alan Wallcraft added velocity relaxation to the nesting scheme and tested it in a strong current regime feeding the Florida Strait. New .08º topographies were created for the Atlantic and IAS HYCOM grids. These differ from the originals in that the coastline is at the 5-meter isobath (instead of 10 meter) and the shallowest depth is 10 meters (instead of 20 meters). A .04º IAS HYCOM topography was also created. All three topographies are derived from the 2-minute global NRL DBDB2 topography developed by D.S. Ko.

Ole Martin Smedstad successfully implemented the first baseline data assimilation scheme into HYCOM in collaboration with Remy Baraille. It presently assimilates satellite altimeter SSH analyses from the MODAS system operational at NAVOCEANO and it vertically projects surface observations using the technique of Cooper and Haines (1996). The assimilation was initially implemented in a .16º Japan-East Sea version of HYCOM. Several identical twin experiments were run with this model to test performance of the assimilation technique. Gregg Jacobs and Hans Ngodock obtained the Ensemble Kalman Filtering software from Geir Evensen and began initial testing and evaluation using a simple reduced gravity model.

RESULTS

With the development of HYCOM 2.1 mostly via collaborative projects, support for global modeling and nested domains has been implemented. The global model includes a bipolar (Pan-Am) grid for the Arctic. HYCOM now includes four widely used mixed layer formulations: Kraus-Turner (Kraus and Turner, 1967), K-Profile Parameterization (Large et al., 1997), Mellor-Yamada 2.5 (Mellor and Yamada, 1982) and Price-Weller-Pinkel (Price et al., 1986).

The .16º Pacific simulations testing horizontal diffusion parameter space have provided important insight into the appropriate form of diffusion needed in HYCOM. Using only biharmonic background diffusion, the Kuroshio tends to prematurely separate from the Japan coast. This problem is resolved using a combination of biharmonic and Laplacian background diffusion. However, additional experimentation is still required to determine the optimal ratios for all diffusion parameters.

Two .08º Pacific simulations forced with different wind sets were integrated long enough to perform a meaningful comparison of model sensitivity to atmospheric forcing. Both are at the point where they can be extended with interannual forcing. Model-data comparisons generally indicate the model is performing well in both the deep and coastal oceans. Based on vertical cross-sections, the model is able to accurately depict the inflow/outflow of the Kuroshio at Luzon Strait. East of Taiwan, the modeled Kuroshio merges from a two-core current system (22ºN) to a single core system (24ºN), as seen in the observations. Farther downstream, the model velocities agree well with observations along the ASUKA line south of Japan. In the tropics, the model depicts the shoaling and strengthening of the Equatorial Undercurrent from west to east, a feature also seen by the TOGA TAO buoy array. But, some differences exist between the experiments. For example, at the PCM-1 mooring line the ECMWF forced simulation (27 Sv) is closer to the observed transport (22 Sv) than the HR forced case (33 Sv). However, the flow in the lee of the Hawaiian Islands is more realistic in the HR forced simulation.

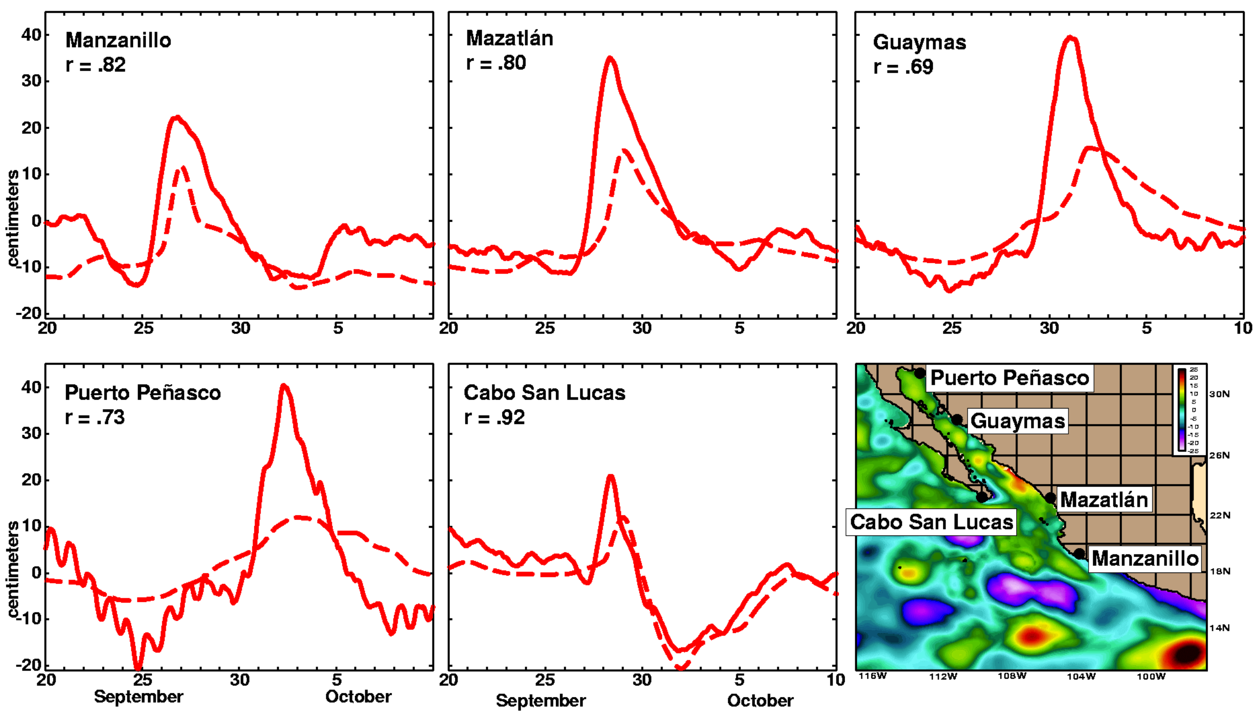

Figure 1: Times series along the Mexican west coast of observed vs. modeled sea level from .08° Pacific HYCOM run with FNMOC NOGAPS winds and thermal forcing. Correlation coefficients are .82 at Manzanillo, .80 at Mazatlán, .69 at Guaymas, .73 at Puerto Peñasco and .92 at Cabo San Lucas. The spatial plot shows the station locations and SSH anomaly for 29 Sept. 2001. Observed sea level data were provided by the U. of Hawaii and the Secretaria de Marina de México.

In the .08° Pacific simulation with interannual forcing, the model is able to accurately depict the generation and propagation of the coastally trapped wave along the Mexican west coast generated by Hurricane Juliette in September-October 2001 (Figure 1). The wave is generated south of Manzanillo and propagates northward into the Gulf of California. Just north of Guaymas, the majority of the signal is reflected southward and travels along the east side of the Baja California peninsula; it is seen as the peak in sea level on 8 October at Cabo San Lucas. After rounding the tip of the peninsula it continues northward. The 29 September peak at Cabo San Lucas is a separate coastally trapped wave generated as Hurricane Juliette tracked over the tip of the peninsula. The sea level response at Puerto Peñasco is related to local wind pileup.

When comparing the DeSoto Canyon and Yucatan Current regions in the 0.32º and 0.08º nested IAS models, a substantial impact is found due to horizontal grid resolution. The 0.08º model is also more realistic due to the generation of frontal eddies along the Loop Current in the Gulf of Mexico. Model-data comparison shows the 0.08º model is approaching the observed Yucatan Current velocity.

A 63 x 59 grid point Florida Straits domain nested at the same grid resolution in the .08° Atlantic HYCOM provided a severe test of baroclinic flows (up to ~1.8 m/s) through the domain boundary. We determined the original baroclinic (relaxation) nesting boundary condition could be improved by a) reducing the minimum e-folding time from 1-day to .1 days and b) by adding relaxation to velocity to the existing 3-D T/S/p relaxation.

IMPACT/APPLICATIONS

HYCOM with data assimilation is planned for use in a fully global, eddy-resolving global ocean prediction system as noted under LONG-TERM GOALS. It will provide boundary conditions to finer resolution coastal models that may use HYCOM or a different ocean model. HYCOM is designed to make optimal use of three types of vertical coordinate, isopycnal, σ and z-level. Isopycnals are the natural coordinate in stratified deep water, terrain-following (σ) coordinates in shallow water and z-levels within 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 should 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. The lead PI is a member of the U.S. and International Steering Teams for the Global Ocean Data Assimilation Experiment (GODAE), a multinational project designed to help justify a permanent global ocean observing system by demonstrating useful near real-time global ocean products.

TRANSITIONS

By FY06, transition the next generation global ocean nowcast/forecast system based on .08° global HYCOM with added capabilities and more advanced data assimilation.

RELATED PROJECTS

Related projects include the multi-institutional NOPP project HYCOM Consortium for Data-assimilative Ocean Modeling (see separate ONR reports), a 6.1 ONR JES DRI project (see separate

ONR report), 6.1 EPIC, 6.1 LINKS, 6.1 Thermodynamic and Topographic Forcing in Global Ocean Models, 6.1 Dynamics of Low Latitude Western Boundary Currents, 6.3 High Fidelity Simulation of Littoral Environments (CHSSI) and 6.4 Altimeter Data Fusion Center (ADFC) Support. The DoD High Performance Computing Modernization Office provided HPC time, including a FY02-04 HPC Challenge grant entitled "Basin-scale Prediction with the HYbrid Coordinate Ocean Model". The lead PI is a member of both the International and U.S. GODAE Steering Teams.

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