HYCOM Consortium for Data-assimilative Ocean Modeling

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LONG-TERM GOALS

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 atmospheric, ice and bio-chemical.

OBJECTIVES

Collaborative 5-year (FY00-04) National Ocean Partnership Program (NOPP) project on the development and evaluation of HYCOM, a scalable and data-assimilative generalized (hybrid isopycnal/terrain-following (σ)/z) coordinate ocean model. Work with collaborators Eric Chassignet (overall project lead PI) and his group at the University of Miami, Rainer Bleck (Los Alamos National Laboratory), Ole Martin Smedstad (Planning Systems, Inc.), Carlisle Thacker (NOAA/Atlantic Oceanographic and Meteorological Laboratory) and Remy Baraille (SHOM). Apply HYCOM to two model domains, an eddy-resolving Atlantic domain (with ~7 km resolution at mid latitudes) and a coarser resolution global domain.

APPROACH

This includes many aspects that will be performed by or in collaboration with consortium partners and partnering projects (five at NRL in FY01).

1. Ocean model design: HYCOM is 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 allows 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).

2. Model development: HYCOM development is a close collaboration between Los Alamos (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/portable and can run on the latest

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14. ABSTRACT

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 atmospheric, ice and bio-chemical.

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computer architectures. Part of this work will be performed under a partnering Common HPC Software Support Initiative (CHSSI) project. HYCOM will be maintained as a single source code with the maximum feasible backward compatibility. Salient issues include the mixed layer and diapycnal mixing, the hybrid coordinate generator, developing a portable and scalable computer code, the capability to run HYCOM in MICOM-mode, the ability to initialize HYCOM from MICOM-mode or a true MICOM simulation, and diagnostic/visualization capabilities. A grid nesting capability is under development in a collaboration between U. Miami and a partnering project at NRL, the 6.2 Global HYCOM and Advanced Data Assimilation project sponsored by ONR (see separate report).

3. Ocean modeling applications: HYCOM will be applied to the Atlantic Ocean (27°S-70°N) in a close collaboration with Eric Chassignet’s group and the global domain in collaboration with Rainer Bleck and Eric Chassignet. HYCOM will be tested on a 1/3° Atlantic model grid consistent with the DYNAMO Experiment before going to high resolution. The HYCOM results will be compared to simulations run in MICOM mode. The high resolution grid is .08° cos θ in latitude (θ) by .08° in longitude or ~7 km resolution for each variable at mid-latitudes. The high resolution Atlantic modeling will be performed mainly using a large grant of computer time provided by an approved FY02-04 DoD High Performance Computing (HPC) Challenge project with Eric Chassignet as the lead PI. NRL participation in the global modeling will begin in FY02 with .72° equatorial resolution. Later it will be increased to .24° and in FY04 to .08° in collaboration with partnering projects. Atmospheric forcing (wind and thermal) will be used from both the European Centre for Medium Range Weather Forecasts (ECMWF) and the National Centers for Environmental Prediction (NCEP). A wide range of data sets are available for model evaluation (Chassignet et al., 2000; Hurlburt and Hogan, 2000) and these papers discuss a wide range of climatological model-data comparisons. In addition, we have long time series of transports through the Florida Straits, sea level at tide gauges, and SST and subsurface temperature from moored buoys; also altimetric sea surface height (SSH) and IR SSTs from satellites, PALACE float and BT data and data from research field programs.

4. Data Assimilation: The HYCOM/NOPP data assimilation effort is mostly performed by consortium partners outside NRL: Ole Martin Smedstad (Planning Systems, Inc., co-located at Stennis), Carlisle Thacker (NOAA/AOML), Arthur Mariano (U. Miami), Mike Chin (JPL/U. Miami) and Remy Baraille in France. Geir Evensen at the Nansen Center in Norway (ensemble Kalman filter method) and Pierre Brasseur in France (SEEK filter method) are also major contributors to the HYCOM data assimilation effort. Under a partnering project, 6.2 HYCOM and Advanced Data Assimilation, Greg Jacobs (NRL) and Hans Ngodock (U. Southern Mississippi and former postdoc of Andrew Bennett) plan to work on HYCOM data assimilation using the representer method and ensemble Kalman filtering, the latter in collaboration with Geir Evensen. The approach is to implement a hierarchy of data assimilation techniques starting with relatively simple and efficient schemes with incremental updating. The first (Ole Martin Smedstad lead) will be an OI-based scheme similar to that used for the NRL Layered Ocean Model (NLOM). The more advanced data assimilation techniques will be evaluated against this baseline. Parameter Matrix Objective Analysis (PMOA) will be investigated as a potential upgrade to the standard OI scheme. PMOA is an OI scheme which is a data-driven analogue of a Kalman filter, one that uses an assumed horizontal covariance model with nine adjustable parameters that can vary in space and time (Mariano and Brown, 1992). The singular evolutive extended Kalman filter (SEEK, Pham et al., 1998) and a reduced order information filter (ROIF, Chin et al., 1999) will also be implemented. Different vertical projections of the surface information to the deep ocean will be evaluated for the assimilation schemes that need them, e.g., Carnes et al. (1990), Hurlburt et al. (1990), Cooper and Haines (1996) and Gavart and DeMey (1996). The techniques will be evaluated for

computational efficiency and accuracy. Complete altimeter data sets from TOPEX/POSEIDON, ERS-2, GFO, JASON-1 and ENVISAT with additional corrections will be available up to real time via NRL; similarly for MCSSTs. In addition, 1/8° mesoscale depicting MODAS analyses of SSH and SST with estimated error fields will be available. The data assimilative model results will be compared with unassimilated data (see #3 above).

WORK COMPLETED

Two meetings of the HYCOM/NOPP partnership were held (Oct. 2000 and March 2001) to review progress and more sharply define the plans and milestones, technical issues, and responsibilities of the participants.

Model development and basic testing: Alan Wallcraft completed development of HYCOM 2.0 with 2-level parallelization, MPI and OpenMP, and FORTAN 90 coding style. It was released for general use on 3 July 2001. The mixed layer options are KPP (Large et al., 1997) and Kraus-Turner and the model can be run in MICOM model as well as HYCOM mode. Alan developed the capability to convert a MICOM-mode or a true MICOM simulation (with layer 1 as a bulk-mixed layer) to initialize a HYCOM simulation with layers added near the surface.

Dan Moore (visiting scientist from Imperial College, London) tested KPP in HYCOM configured as a one-dimensional model against Mellor-Yamada as implemented in the Navy Coastal Ocean Model (NCOM). He also performed tests using an x-z plane upwelling/downwelling model. The model includes shelf regions on both sides and was forced by a uniform northward wind stress. These tests were performed by running HYCOM with different vertical coordinates and resolutions: pure z-level, pure σ, hybrid σ-z and hybrid isopycnal-σ-z. The horizontal resolutions ranged from 2-10 km in the horizontal and from 15-50 coordinate surfaces in the vertical. The results were compared with corresponding results in Martin (1998) for the Princeton Ocean Model (POM) and SZM (the forerunner of NCOM).

Model applications: Pat Hogan ran several .32° Atlantic simulations for 10 years or more starting from climatology or a previous run, a few in MICOM mode for comparison to HYCOM. One was run 1979-2000 with 6 hourly atmospheric forcing from ECMWF. The 1/12° HYCOM Atlantic modeling is a major component of the HYCOM/NOPP project and is a collaborative effort between NRL and U. Miami. In support of this effort an FY02-04 DoD High Performance Computing (HPC) Challenge project was obtained with Eric Chassignet as the lead PI. In preparation, the first 1/12° Atlantic HYCOM simulation was initialized from Eric's best 1/12° MICOM simulation, which has a very realistic Gulf Stream pathway between Cape Hatteras and the Grand Banks. This test simulation was run for 74 days after intialization from MICOM and is illustrated in the figure. Work is underway on appropriate sampling of both the HYCOM and MICOM simulations.

Data assimilation: Pat Hogan (NRL) prepared a tar file with HYCOM 2.0 bundled with everything required to continue one of his .32° Atlantic simulations and use it in data assimilation and testing. This file was provided to Remy Baraille in France, Mike Chin at JPL/U. Miami and Ole Martin Smedstad at PSI-Stennis.

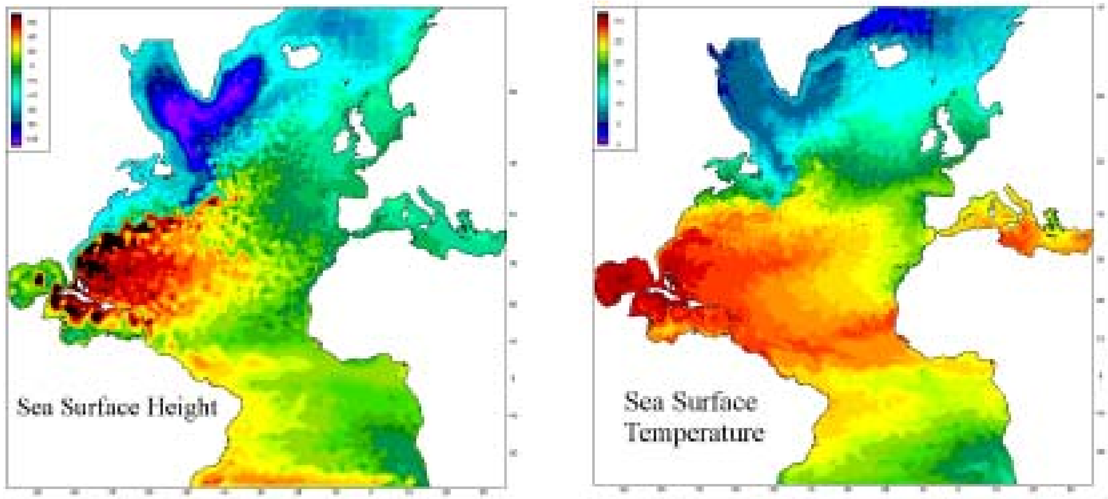

Figure caption: Snapshots of sea surface height (SSH) and sea surface temperature (SST) from a 1/12° HYCOM Atlantic Ocean simulation for 29 August, 68 days after initialization from MICOM. The simulation has ~7 km mid-latitude resolution and was atmospherically forced by a monthly mean ECMWF reanalysis climatology plus relaxation to an oceanic climatology at the northern and southern boundaries to include the global thermohaline circulation.

RESULTS

The collaborative HYCOM effort including the HYCOM/NOPP consortium, partnering projects and the broader international community effort is working extremely well.

Model development and basic testing: At the beginning of FY01 HYCOM 1.0 was a limping new model with limited parallelization via OpenMP. With the release of HYCOM 2.0 it has reached the maturity required for broad application. It is scalable up to O(1000 cpus) via two levels of parallelization, either or both of which can be used, and it can run on computing platforms ranging from PCs to a variety of supercomputers with different parallel architectures. This was accomplished using a single source code for all machine types. HYCOM 2.0 has MICOM compatibility, an asset in comparing the two models and initializing HYCOM from existing MICOM simulations.

In testing HYCOM, Dan Moore found that KPP in HYCOM gave results very similar to Mellor-Yamada in NCOM or POM when the KPP parameter values were appropriately chosen (although these are not necessarily the values that would be chosen for a typical HYCOM simulation). KPP is a full water column diapycnal mixing/diffusion scheme, a particularly valuable asset for an ocean model which includes isopycnals as a vertical coordinate. Apriori, we were concerned that HYCOM might not perform as well in σ and z-coordinate mode as models designed specifically for these coordinates. However, HYCOM performed very well and robustly using these coordinates in comparison to NCOM and POM. As an advantage, it avoids stairstep topography in z-coordinate mode and is more flexible in hybrid σ-z coordinate mode than NCOM.

Model applications: The .32° HYCOM results compare favorably with those from MICOM and even show a Gulf Stream inertial segment with the correct separation at Cape Hatteras much of the time, a capability not seen in the corresponding MICOM mode simulation. The 1/12° HYCOM Atlantic modeling is the central high resolution modeling component of the HYCOM/NOPP project. The ability to initialize HYCOM from Eric Chassignet's best MICOM simulation and the short 74-day 1/12° Atlantic HYCOM test run are a valuable head start on the FY02-04 DoD HPC Challenge project which will provide the computer time required for 1/12° HYCOM Atlantic modeling. The HYCOM and MICOM sampling is designed for HYCOM and MICOM comparison as well as comparisons to observations. Particular emphasis is placed on comparisons relevant to the Gulf Stream, which MICOM simulated well, but which is difficult to simulate accurately even at ~7 km resolution. If the HYCOM simulation does not perform as well, the comparisons should help us diagnose and correct the problems that arise.

Data assimilation: Using the HYCOM 2.0/.32° HYCOM Atlantic tar file provided by Pat Hogan, Remy Baraille has already implemented the Cooper and Haines (1996) technique for downward projection of sea surface height data into HYCOM and he has provided it to HYCOM/NOPP partner Ole Martin Smedstad. With the addition of this component, Ole Martin has everything needed to develop a baseline HYCOM data assimilation capability for satellite altimeter data.

IMPACT/APPLICATIONS

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 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 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. HYCOM is a new and promising design for next generation global and regional ocean prediction systems and it extends the range of application for ocean models in research. The NRL PI and Eric Chassignet (U. Miami) are members 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 ocean products.

TRANSITIONS

None.

RELATED PROJECTS

The HYCOM/NOPP consortium includes E.P. Chassignet (Coordinator), A. Mariano, G. Halliwell, and T.M. Chin (JPL/U. Miami), R. Bleck (LANL), H. Hurlburt, A. Wallcraft, P. Hogan, R. Rhodes, and G. Jacobs (Naval Research Laboratory), O. M. Smedstad (Planning Systems, Inc.), W.C. Thacker (NOAA/AOML) and R. Baraille (SHOM). Partnering projects at NRL include an NRL 6.1 ONR JES DRI project, 6.1 LINKS, 6.1 Thermodynamic and Topographic Forcing in Global Ocean Models, 6.2 Global HYCOM and Advanced Data Assimilation, 6.3 High Fidelity Simulation of Littoral Environments (CHSSI)) and 6.4 ADFC Support. Additionally, the project receives grants of HPC time from the DoD High Performance Computing Modernization Office. The NRL PI is a member of both the International and U.S. GODAE Steering Teams.

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