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 littoral, 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) coordinate ocean model which includes, but is not limited to isopycnal, terrain-following (σ), and pressure (approximately fixed-depth z-level) coordinates. 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 of the ocean modeling that will be performed by or in collaboration with consortium partners and partnering projects (four at NRL in FY04). The data assimilation components are covered in other HYCOM related ONR reports.

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), Bleck and Benjamin (1993), Bleck (2002) and Halliwell (2004).

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. The NASA Goddard Institute for Space Studies (GISS) is an outside collaborator contributing in the areas of thermobaricity (Shan Sun) (a topic discussed by Chassignet et al., 2003) and addition of the GISS mixed layer model (Canuto et al., 2004). 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 computer architectures. Part of this work has been performed under a partnering Common HPC Software Support Initiative (CHSSI) project. HYCOM is 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 the FY04-FY08 NOPP project U.S. GODAE: Global Ocean Prediction with the HYbrid Coordinate Ocean Model (HYCOM) and the 6.2 project Coastal Ocean NESTing Studies (CO-NESTS) funded by ONR via the NRL base program.

3. Ocean modeling applications: HYCOM is being used to model the Atlantic Ocean (28°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 was tested on a .32° Atlantic model grid consistent with the DYNAMO Experiment before going to .08° resolution. The .08° grid is .08° cos θ in latitude (θ) by .08° in longitude or ~7 km resolution for each variable at mid-latitudes. The .08° Atlantic modeling has mainly used a large grant of computer time provided by an FY02-04 DoD High Performance Computing (HPC) Challenge project with Eric Chassignet as the lead PI and time from NRL's HPC allocation on a dedicated 512-cpu SGI Origin 3900. NRL participation in the global modeling began in FY02 with .72° equatorial resolution. In FY04 a short test run at .08° was run in collaboration with partnering projects. Atmospheric forcing (wind and thermal) is from the European Centre for Medium Range Weather Forecasts (ECMWF) and the Fleet Numerical Meteorology and Oceanography Center (FNMOC) Navy Operational Global Atmospheric Prediction System (NOGAPS). 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 sea surface temperature (SST) and subsurface temperature from moored buoys; also altimetric sea surface height (SSH), ocean color and IR SSTs from satellites, PALACE float and BT data, and data from research field programs.

WORK COMPLETED

A meeting of the HYCOM/NOPP partnership was held in Feb. 2004 to review progress and update the plans and milestones, technical issues, and responsibilities of the participants. This included a new NOPP/Global Ocean Data Assimilation Experiment (GODAE) project, U.S. GODAE: Global Ocean Prediction with HYCOM which began later in FY04.

Model development and basic testing: Development included contributions from other NOPP/HYCOM consortium partners (see separate ONR reports) and 6.2 Coastal Ocean NESTing Studies (CO-NESTS). The most significant improvement to HYCOM in FY04 was the addition of several scalar field advection options, with 2nd-order FCT replacing MPDATA as the "standard" advection method because it significantly reduces numerical noise at high resolution. This has greatly improved the 1/12° Atlantic simulations, which previously (with MPDATA) had an overturning circulation nearly double that observed due to excessive deep mixing at high latitudes. Additions to HYCOM primarily for coastal regions include better support for rivers (still treated as precipitation) and the option to include a bottom boundary layer when the KPP mixed layer is used. Atmospheric forcing upgrades include improved bulk parameterizations for wind stress and latent/sensible heat fluxes (especially at high and low wind speeds) (Kara and Hurlburt, 2004), finer control over how u* is calculated, better support for reading in total heat flux and/or E-P (rather than using a bulk heat flux parameterization), and the option to relax to observed sea surface temperature. The coefficients used in Kara and Hurlburt (2004) are tuned for agreement with the state-of-the-art COARE 3.0 algorithm of Fairall et al. (2003). In addition, a new shortwave radiation penetration scheme (dual exponential based on the red and blue bands) was implemented in HYCOM and is used in combination with a global monthly k_{PAR} climatology based on satellite data from SeaWIFS. Model files still use a raw binary format, for optimal I/O performance, but diagnostic packages can output netCDF and several other common file formats. These include fields in hybrid layer space, or interpolated to a fixed z-grid in the vertical, or sampled along arbitrary tracks. One output option is a MERSEA-compatible netCDF file to facilitate our participation in the European MERSEA Atlantic prediction system intercomparison project.

Work is continuing on fully global HYCOM at 0.72° equatorial resolution with doubled latitudinal resolution near the equator. This is about the finest resolution possible on a non-eddy resolving grid and is well suited to SST and mixed layer studies except for poorly resolved coastal features and around inertial jets, e.g. associated with western boundary currents. A HYCOM Black Sea model with ~3.2 km resolution was also used for some of these investigations. Because of the Black Sea's high turbidity, it was especially useful in testing effects of solar penetration.

Atlantic modeling (28°S-70°N): In addition to changing the scalar advection scheme, as described above, simulations performed included (1) some with the potential temperature reference depth at the surface (σ_0) and some at 2 km with thermobaricity (σ_2*), with the latter simulations also having deeper z-levels (a modification suggested by 0.32° results at high latitudes); (2) use of spatially-varying Lagrangian layer target densities in the σ_0 simulations such that appropriately denser isopycnal layers could be used in the Mediterranean Sea; and (3) improved KPP parameterizations in both the σ_0 and σ_2* simulations. All used a KPP mixed layer (Large et al., 1997). Most .08° simulations were performed on a dedicated 512-cpu SGI Origin 3900 with others using part of a large FY02-04 DoD High Performance Computing Challenge grant. Both the NRL group and Eric Chassignet's group at the University of Miami contributed to the design and execution of the Atlantic simulations and to the analysis of the results. The .08° Atlantic data-assimilative nowcast/forecast system has continued running in near real-time with the results on the project website http://hycom.rsmas.miami.edu (see separate NOPP/HYCOM/PSI ONR report for details about the system).

RESULTS

The newly funded NOPP/GODAE HYCOM project is designed to help take HYCOM from the research and development performed under this NOPP project to development of operation eddy-resolving global and basin-scale ocean prediction systems for the U.S. Navy and NOAA, both NOPP projects in collaboration with partnering projects. This effort will also provide the ocean component of coupled ocean-atmosphere prediction systems and boundary conditions for regional and coastal models. The NOPP projects are essential to this collaborative multi-agency/university/industry/ international effort and such collaboration is essential to the success of an effort with the scope and complexity of this one.

Three K-profile mixed layer models (KPP, GISS, and Mellor-Yamada level 2.5 (Mellor and Yamada,1982)) were compared in the .72° fully global HYCOM. Comparisons to 166 year-long daily buoy SST time series over 1996-2001 gave median RMS differences of 0.70°C for KPP, 0.76°C for GISS, and 0.85°C for Mellor-Yamada 2.5. During the 1998 transition from El Niño to La Niña, SST decreased ~7°C within one month in the eastern equatorial Pacific. In HYCOM, GISS and KPP greatly outperformed Mellor-Yamada in making this transition. We continue to use KPP as our standard mixed layer model.

The 3.2 km resolution HYCOM simulations of the turbid Black Sea demonstrate the need for properly including a solar subsurface heating parameterization in ocean models, especially for accurate simulation of SST, mixed layer depth (MLD), and stratification at the base of the mixed layer. This can greatly affect the accuracy of subsurface temperature profiles and their vertical structure. For example, using the solar penetration scheme described in the preceding section and comparisons to a monthly Pathfinder SST climatology, the overall Black Sea rms deviation of the simulated SST rose 46% from 1.41°C when using the monthly k_{PAR}-based turbidity climatology from SeaWIFS data to 2.06°C when clear water (k_{PAR}=.06 m^{-1}) was used, both in combination with atmospheric forcing from a high-frequency climatology derived from the ECMWF reanalysis of Gibson et al (1997). Similarly it rose 36% from 1.39°C to 1.89°C when forcing from the FNMOC NOGAPS (Rosmond et al., 2002) was used (Kara et al., 2004b,c). In addition, Kara et al. (2004a) found that using the SeaWIFS-based turbidity climatology greatly improved the MLD and the stratification at the base of the mixed layer in comparison to the annual mean of the MODAS climatology (Fox et al., 2002). When clear water was used, the MLD was too deep and the stratification at the base of the mixed layer was greatly weakened due to excessive solar heating below the mixed layer.

Reducing the numerical noise at high resolution by switching to the 2nd-order FCT scalar advection option gave much improved MOC amplitude and subpolar gyre circulation/vertical structure in the .08° Atlantic HYCOM. This is due to the elimination of excessive vertical mixing and loss of stratification in the subpolar gyre region of the high-resolution model. The resulting meridional overturning circulation (MOC) amplitude (Figure 1a.) is in excellent agreement with the observationally-based estimate of ~14 Sv for the northward upper branch (Schmitz and Richardson, 1991). In simulations using MPDATA it was much too strong at approximately twice the observed value. However, in the σ_0 simulations the depth of the switch from northward to southward flow (Figure 1b.) is still too deep, (>1200m) south of 20°N. In the σ_2* simulations (which also used 2nd-order FCT for scalar advection), the depth of this switch in direction of net flow in the MOC is between 1000m and 1200m south of 20°N. This is much closer to what it should be to allow the upper northward portion of the MOC to flow into the Caribbean Sea as observed (Schmitz and Richardson, 1991).

The advantage of using an isopycnal coordinate in the stratified interior is clearly demonstrated by the uniform transport of the MOC from the southern buffer zone to the subpolar Atlantic, where North Atlantic Deep Water (NADW) formation occurs. This results because a Lagrangian isopycnal coordinate avoids the spurious diapycnal diffusion that plagues non-Lagrangian coordinates, such as fixed-depth (z-level) and terrain-following (σ) coordinates, e.g. see Fig. 2 of the overview paper about the ONR-sponsored Data Assimilation and Model Evaluation Experiment-North Atlantic Basin (DAMEE-NAB) (Chassignet et al., 2000). In the σ_0 simulations, implementing different Lagrangian layer target densities in the Mediterranean Sea from those in the Atlantic Ocean vastly improved the model circulation within the Mediterranean Sea. While spatially-varying target densities have not yet been implemented in σ_2* simulations, the Mediterranean results are also significantly improved over the original σ_0 results due to the different z-level distribution (z-levels down to about 1500m).

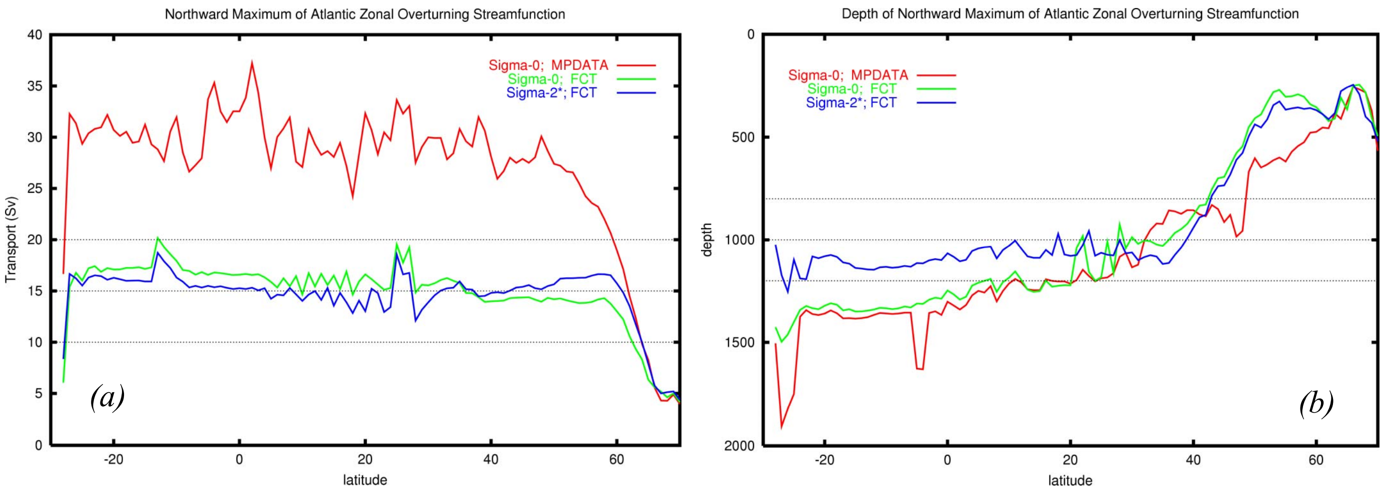

Figure 1. (a) Zonally-averaged northward transport (Sv) of the meridional overturning cell (MOC) vs. latitude, transport occurring above (b) the depth of the switch from net northward flow in the upper ocean to net southward flow below in the .08° Atlantic HYCOM using σ_0 coordinates with MPDATA (red) and FCT (green), and σ_2* coordinates with FCT (blue). The MOC amplitude is too strong in the simulation with MPDATA, but in excellent agreement with observations in simulations with FCT advection. The switch from northward (upper) to southward (deep) flow is too deep in both the MPDATA and FCT σ_0 simulations, but much more realistic in the σ_2* FCT simulation.

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 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 global ocean products.

TRANSITIONS

None.

RELATED PROJECTS

The HYCOM/NOPP consortium includes E.P. Chassignet (Coordinator), A. Mariano, G. Halliwell (U. Miami), 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 6.1 Dynamics of Low Latitude Western Boundary Currents, 6.2 Global HYCOM and Advanced Data Assimilation, 6.2 Coastal Ocean NESTing Studies (CO-NESTS), and 6.4 Altimeter Data Fusion Center (ADFC) Support. Additionally, the project received grants of HPC time from the DoD High Performance Computing Modernization Office, including a dedicated node on the SGI Origin 3900 at the Aeronautical Systems Center and an FY02-04 HPC challenge grant entitled "Basin-scale ocean prediction with the HYbrid Coordinate Ocean Model" on the IBM SP3 at the Naval Oceanographic Office. The NRL PI is a member of the International and U.S. GODAE Steering Teams.

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