# Hycom Consortium For Data Assimilative Ocean Modeling

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## LONG-TERM GOALS

Development of a consortium for hybrid-coordinate data assimilative ocean modeling, which will be ready in 2003 to address both the US-GODAE (Global Ocean Data Assimilation Experiment) principal objective, i.e., the depiction of the three-dimensional ocean state at fine resolution in near-real time, and the climate modeling objective of producing an unbiased estimate of the state of the ocean at coarse resolution for long-term climate variability research.

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 Remy 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.

## APPROACH

- Hierarchy of model configurations from fully global to regional/coastal

- Coarse resolution model-based reanalysis of archived observational data will provide a comprehensive picture of the dynamics and thermodynamics of the global ocean during recent decades;

- Expertise on the model's behavior with an eddy-resolving grid will be gained by running the model in basin-scale configurations using lateral boundary conditions provided by the global simulations.

- Sophisticated data assimilation techniques

## WORK COMPLETED

a) Release of HYCOM 2.0

b) Global, basin-scale, and regional simulations

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14. ABSTRACT
**Development of a consortium for hybrid-coordinate data assimilative ocean modeling, which will be ready in 2003 to address both the US-GODAE (Global Ocean Data Assimilation Experiment) principal objective, i.e., the depiction of the three-dimensional ocean state at fine resolution in near-real time, and the climate modeling objective of producing an unbiased estimate of the state of the ocean at coarse resolution for long-term climate variability research.**

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c) Data assimilation capabilities

**RESULTS**

The HYCOM Consortium for Data Assimilative Ocean Modeling is a multi-institution effort (see above for details). This report mostly focuses on work that was performed at (or in collaboration with scientists at) the University of Miami. The reader is referred to the complementary reports of H. Hurlburt (NRL), O.M. Smedstad (Planning Systems, Inc.), and C. Thacker (NOAA) for a complete overview of the NOPP-funded effort.

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 (2001) for details].

HYCOM 2.0 was recently released 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). HYCOM 2.0 now includes the following: Fortran 90 style codes, MPI/SHMEM or OpenMP selectability at compile time, halos for MPI to automatically support periodic boundaries, nested-domain open boundaries, fully global, and NetCDF output files (see http://hycom.rsmas.miami.edu for details).

The capability of assigning additional coordinate surfaces to the oceanic mixed layer gives us the option of replacing the slab-type Kraus-Turner mixed layer of MICOM by a more sophisticated closure scheme in HYCOM, such as K-Profile Parameterization (KPP) (see Large et al., 1997). Both mixed layer parameterizations are available in HYCOM 2.0.

The KPP mixing algorithm has several advantages: It provides mixing throughout the water column with an abrupt but smooth transition between the vigorous mixing in the surface boundary layer and the relatively weak diapycnal mixing in the ocean interior. It works on a relative coarse and unevenly-space vertical grid. It parameterizes the influence of a larger number of physical processes that other commonly used mixing schemes. In the ocean interior, the contribution of background internal wave breaking, shear instability mixing, and double diffusion (both salt fingering and diffusive instability) are parameterized. In the surface boundary layer, the influences of wind-driven mixing, surface buoyancy fluxes, and convective instability are parameterized. The KPP algorithm also parameterizes the influence of nonlocal mixing of T and S, which permits the development of countergradient fluxes. A detailed description of the KPP algorithm is available on the HYCOM web site and a manuscript is under preparation (Halliwell et al., 2001). An alternative to the KPP algorithm, proposed by Canuto (2001), was also implemented in HYCOM 2.0 by post-doctoral associate A. Romanou and is under evaluation.

HYCOM 2.0 has been configured globally, on basin scales, and regionally. The fully global configuration (resolution of 1$^{\circ}$) is currently being evaluated by R. Bleck (Los Alamos) and S. Sun (NOAA). A HYCOM/MICOM comparison is available from the HYCOM web site. The North Pacific basin-scale simulations are based on simulations previously performed with NLOM (see H. Hurlburt's report for details). The North Atlantic basin-scale simulations are based on the Community Modeling Experiment (CME), DYNAMO, and MICOM experiences (1$^{\circ}$, 1/3$^{\circ}$, and 1/12$^{\circ}$ 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. Previous studies with MICOM-based North Atlantic simulations (Chassignet et al., 1996; Smith et al., 2000) have focused on comparisons to observations, to results obtained from depth-coordinate simulations and on the impact of lateral boundary conditions and horizontal grid resolution in relation to the water mass transformations and pathways simulated by the model. By taking advantage of the built-in vertical coordinate flexibility of HYCOM, we assessed the importance of the vertical coordinate choice on the model results. We first compared the HYCOM results to those from MICOM with identical basin configuration, forcing, and lateral boundary conditions. We then focused on determining the effect of the coordinate representation of density ($\sigma_\theta$, $\sigma 2$, $\sigma 2$ with thermobaricity) on the model's ability to accurately represent the water mass distributions and three-dimensional circulation of the Atlantic. A manuscript is under preparation (Chassignet et al., 2001).

The NRL group has run several 1/3$^{\circ}$ Atlantic simulations for 10 years or more, including climatological and interannual with high frequency atmospheric forcing and HYCOM mode vs MICOM mode. The 1/3$^{\circ}$ HYCOM results compare favorably those from MICOM and even show a Gulf Stream inertial segment with correct separation at Cape Hatteras much of the time, a capability not seen in the corresponding MICOM mode simulation. HYCOM 2.0 bundled with a 1/3$^{\circ}$ degree Atlantic simulation is our official test bed for use in data assimilation development and evaluation. It is available from the HYCOM web site and is presently being used by data assimilation consortium members R. Baraille and M. Chin.

The 1/12$^{\circ}$ HYCOM Atlantic domain is a major component of our HYCOM effort since the ultimate goal is a transition to a 1/12$^{\circ}$ global ocean prediction system in 2006. In close collaboration with H. Hurlburt's group, the first 1/12$^{\circ}$ Atlantic HYCOM simulation was recently initialized from the latest 1/12$^{\circ}$ MICOM simulation, which has a very good Gulf Stream pathway. It was run for 74 days and, as shown in Fig. 1, there is no degradation of the surface fields during that time. We are presently working on appropriate sampling of both the HYCOM and MICOM simulations, especially for comparisons that are relevant to the Gulf Stream.

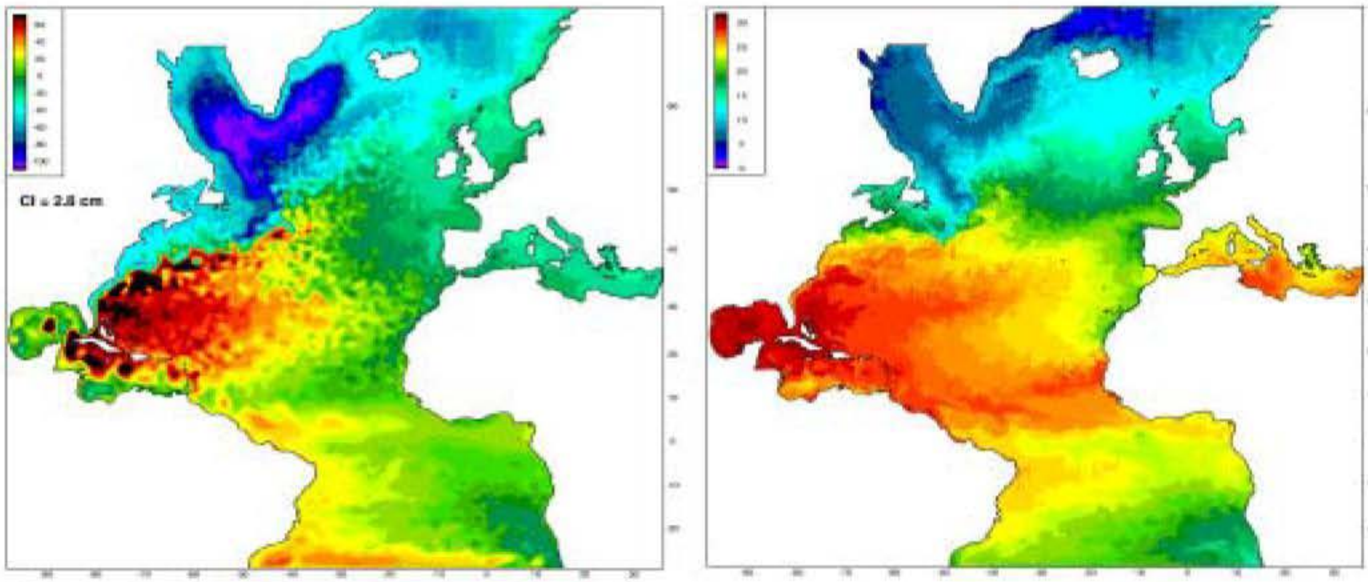

***Fig. 1: Snapshots of the 1/12° HYCOM 74 days after being initialized from the latest ECMWF MICOM run. There is no degradation in the surface fields. Left panel: Sea surface height. Right Panel: Sea surface temperature.***

For assimilation of surface altimetry data, the Reduced Order Information Filter (ROIF) has been ported from MICOM to the HYCOM coordinate system. ROIF is a reduced order implementation of Kalman filter that has been shown (Chin et al., 1999; 2001) to be effective in observation system simulation experiments (twin experiments) for assimilation of sea surface heights sampled sparsely as in the Topex/Poseidon satellite. The assimilation technique has also been proven mathematically to preserve positive definiteness in the approximated covariance matrix (Chin, 2001).

Porting of ROIF assimilation system from MICOM to HYCOM is achieved by converting its vertical axis from one that based on layer-thickness to a pressure-based coordinate. The HYCOM-adapted ROIF was tested first in a 2° x 2°grid model of North Atlantic with the KPP mixing scheme. Preliminary analysis show that the sea surface height field converges exponentially towards the truth (a twin run) through assimilation of the sparsely sampled (TOPEX/Poseidon track) data. This result is consistent with the previous performance with MICOM.

Further examination of the HYCOM-adapted ROIF is underway. Our agenda is to perform (i) quality checks of the new ROIF numerics, e.g., matrix conditioning, (ii) an evaluation of the vertical profiling and its sensitivity to the prior/empirical statistics, (iii) an evaluation with the finer resolution HYCOM, i.e., 1/3° North Atlantic configuration.

In addition to ROIF, the consortium is evaluating an Optimal Interpolation (OI) scheme combined with a Cooper-Haines vertical projection of the surface information (put in place by O.M. Smedstad and R. Baraille) and (2) the Reduced Order Adaptive Filter (ROAF) (Hoang et al., 1997), which estimates unknown parameters by minimizing the forecast error; this technique requires the model's adjoint (developed and parallelized by R. Baraille).

At the present time, only the Cooper and Haines (1996) OI scheme has been implemented in the 1/3° test configuration. Both the ROAF and ROIF are being transitioned to 1/3° North Atlantic configuration. The three data assimilation schemes will be evaluated in a series of twin and near-real-time data assimilation experiments. G. Evensen, one of our NOPP collaborator, has also expressed an interest in participating in this evaluation exercise with his HYCOM Ensemble Kalman Filter (http://www.nrsc.no/~geir/hycomstuff.html ) which is already operational.

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 currently evaluating its performance and the HYCOM outputs will soon be available on the server.

## IMPACT/APPLICATIONS

Generation of optimal estimates of the time-varying ocean state in support of the 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).

## TRANSITIONS

None

## RELATED PROJECTS

This effort is part of a multi-institutional NOPP project which includes E. Chassignet (Coordinator), G. Halliwell, and A. Mariano (U. of Miami/RSMAS), T. 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 Remy Baraille (SHOM).

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