Predicting "Ocean Weather" Using the 1/12° Global HYbrid Coordinate Ocean Model (HYCOM)[1]

By E. J. Metzger, H. E. Hurlburt, A. J. Wallcraft, Naval Research Laboratory; O. M. Smedstad, QinetiQ North America/Planning Systems, Inc.; J. A. Cummings, Naval Research Laboratory; and E. P. Chassignet, Florida State University

Introduction

The development of an advanced global ocean prediction system has been a long-term Navy interest. Such a system must provide the capability to depict (nowcast) and predict (forecast) the oceanic "weather," some components of which include the 3-D temperature (T), salinity (S) and current structure, the surface mixed layer, and the location of mesoscale features such as eddies, meandering currents, and fronts. The space scale of these eddies and meandering currents is typically ~100 km, and current speeds can easily exceed 1 ms^{-1} in the Gulf Stream (Atlantic Ocean) and Kuroshio (Pacific Ocean). Numerical ocean models with sufficiently high horizontal and vertical resolution are needed to depict the 3-D structure with accuracy superior to climatology and persistence (i.e., a forecast of no change). The accelerated development of these prediction systems would not have been possible without the computational resources provided by the DoD HPCMP. Throughout the research and development stages of numerical ocean models and data assimilation techniques, HPC has played a key role. This is especially true with regard to grand challenge projects that allowed development of high horizontal resolution global systems long before it became feasible to run them in an operational environment. In addition, nonchallenge and Capability Application Projects have also provided considerable resources toward advancement of these systems.

The existing two-model operational global ocean prediction system, run daily at the Navy DSRC, is based on the 1/8° Navy Coastal Ocean Model (NCOM) and the 1/32° Navy Layered Ocean Model (NLOM). Unlike NLOM, NCOM has high vertical resolution, but it has medium-range horizontal resolution (~15 km at mid-latitudes near 40°N), which makes it eddy-permitting. The next-generation system is based on a single model, the HYbrid Coordinate Ocean Model (HYCOM) (Bleck, 2002). It was developed as part of a multi-institutional consortium between academia, Government, and private industry. At 2.2 times the horizontal resolution of NCOM, the HYCOM-based system is eddy-resolving, a distinction associated with important dynamical implications for both ocean model dynamical interpolation skill in the assimilation of ocean data and for ocean model forecast skill (Hurlburt et al., 2008). HYCOM is also uniquely designed to allow an accurate transition between deep and shallow water, historically a challenging problem for ocean models. Its generalized hybrid vertical coordinate is a substantial advance over the vertical coordinate system

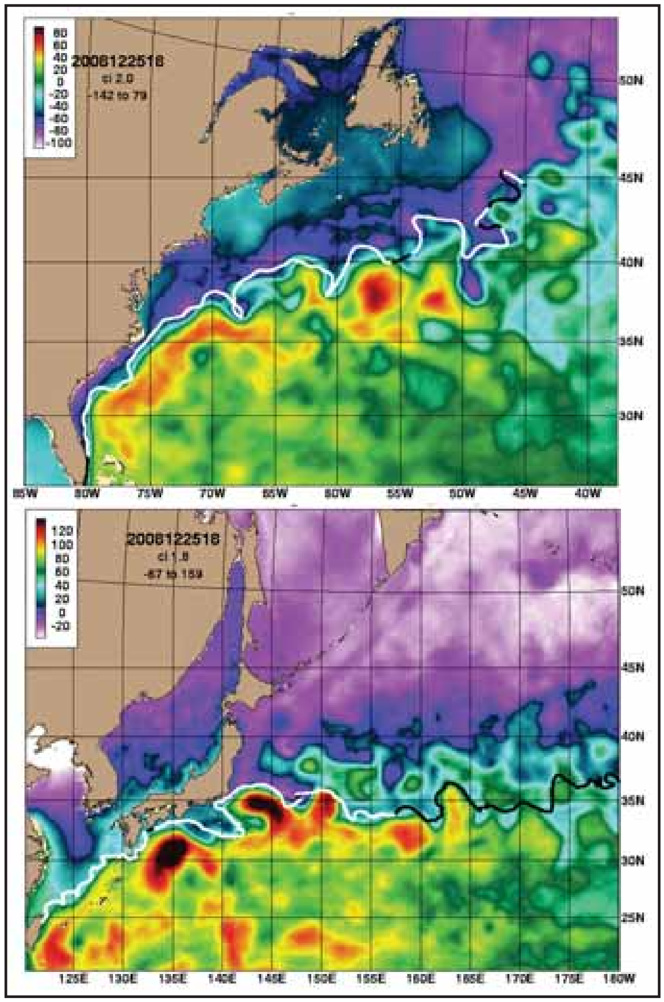

Figure 1. Sea surface height (cm) from the 1/12° global HYCOM prediction system for the Gulf Stream in the Atlantic Ocean (top) and the Kuroshio in the Pacific Ocean (bottom) on December 22, 2008. The ribbon of high gradient color shows the location of these western boundary currents; embedded within the meandering flow are warm and cold core eddies. The currents generally flow parallel to the isolines of height and are strongest where the gradients are the tightest. An independent infrared (IR) analysis of the north edge of both current systems is performed by NAVO and overlain on each image. A white (black) line means the IR analysis is based on data less (more) than 4 days old

[1] *HPC Insights* is reprinting this article, as essential information was inadvertently deleted in its last issue.

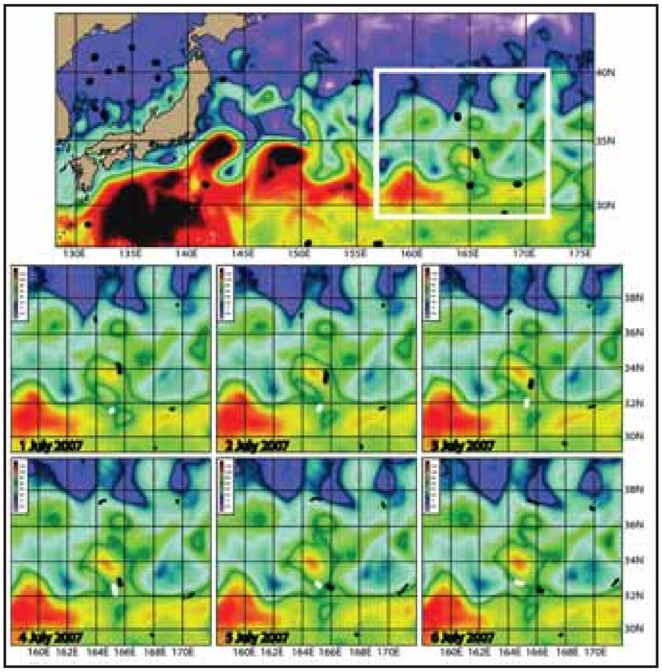

Figure 2. Sea surface height (cm) from the 1/12° global HYCOM prediction system for the Kuroshio on July 1, 2007 (top). Drifting buoy tracks over a 1-day time period are overlain on each panel. The white box defines the focused area of the bottom six panels that span the time frame July 1-6, 2007. A warm core eddy is about to detach from the Kuroshio, and two drifting buoys (highlighted in white and black) are traversing its western and eastern sides

used in NCOM. The HYCOM-based system represents the world's first eddy-resolving global ocean prediction system with both high horizontal and vertical resolution and has been validated against observational data (Metzger et al., 2008). It is scheduled for operational testing in 2009.

HYCOM Description

HYCOM is on a 1/12° global grid (mid-latitude resolution of ~7 km) with 32 hybrid vertical coordinate surfaces. The truly generalized vertical coordinate can be isopycnal (density tracking – often best in the deep stratified ocean), levels of equal pressure (nearly fixed depths – best used in the mixed layer and unstratified ocean), or terrain-following (often the best choice in shallow water). HYCOM combines all three approaches by choosing the optimal distribution at every grid point and time-step. The hybrid coordinate extends the geographic range of applicability of traditional isopycnic coordinate models toward shallow coastal seas and unstratified parts of the world ocean. It maintains the significant advantages of an isopycnal model in stratified regions while allowing more vertical resolution near the surface and in shallow coastal areas, hence providing a better representation of the upper ocean physics.

HYCOM employs the Navy Coupled Ocean Data Assimilation (NCODA) (Cummings, 2005), which is a fully 3-D multivariate optimum interpolation scheme, to assimilate observational data. The data include surface observations from satellites, including altimeter sea surface height (SSH) anomalies, sea surface temperature (SST), and sea ice concentration, plus *in situ* SST observations from ships and buoys as well as T & S profile data from XBTs, CTDs, and Argo profiling floats. The 3-D ocean environment can be more accurately nowcast and forecast by combining these diverse observational data types via data assimilation and using the dynamical interpolation skill of the model.

The 1/12° global HYCOM-based prediction system has been running daily in pre-operational mode at the Navy DSRC since December 22, 2006. Originally running on the IBM machines (*Romulus* – Power4+ and then *Babbage* – Power5+), the system was recently moved to the Cray XT5 (*Einstein*). Here it is presently configured to use 78 nodes (619 processors) to run HYCOM and produce the NCODA analyses with an additional two nodes set aside for pre- and postprocessing.

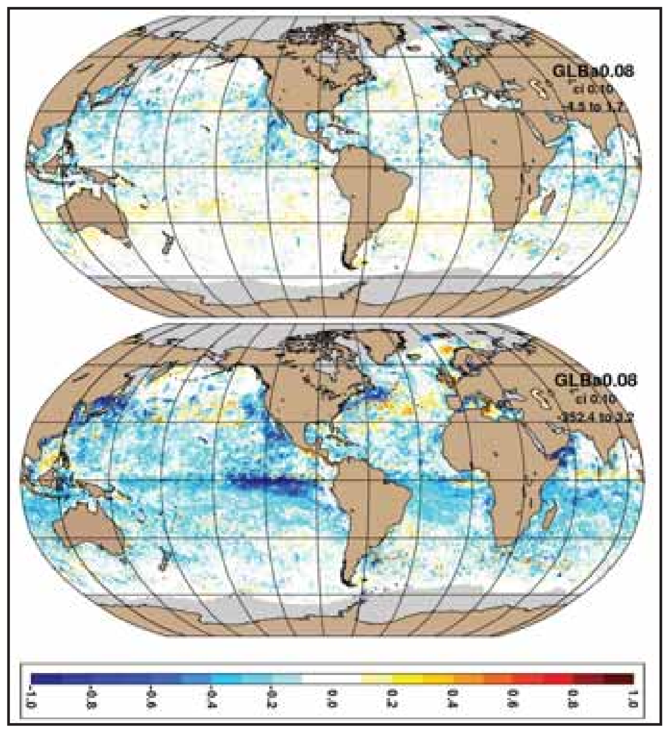

Figure 3. Sea surface temperature (SST) mean error relative to ~33,000,000 MCSST observations from the 1/12° global HYCOM prediction system at the analysis time (top) and for a 3-day forecast (bottom) over a year-long hindcast spanning June 2007-May 2008. Red (blue) colors indicate nowcast and forecast SST that is warmer (cooler) than observed. Values between ±0.1˚C are white. The gray area near the poles is an annual average ice coverage mask

HYCOM efficiently scales to large processor counts and can easily be configured to fit within the allocated resource window. Each day the system starts 5 days in arrears of the nowcast time (to assimilate all available late-arriving observational data) and then runs forward to create a 5-day forecast. It generates 3-D whole domain instantaneous archive files at 00Z each model day that are ~10 Gb.

Real-Time Results

Where possible, the HYCOM-based prediction system is evaluated using independent observations, and some examples follow. Figure 1 shows simulated SSH for the Gulf Stream and the Kuroshio systems. The assimilation of satellite altimeter SSH anomalies is essential to accurately map the circulation in these highly chaotic regions dominated by mesoscale flow instabilities. Infrared-based frontal analyses that show the northernmost edge of the currents are overlain on the panels. They provide an independent analysis of the current positions and clearly indicate the ocean nowcast/forecast system is accurately mapping these western boundary currents. Figure 2 shows an example that uses drifting buoy trajectories to validate the flow field in the Kuroshio. Drifting buoy temperature (but not velocity) is assimilated via NCODA, allowing the trajectory to be an independent validation source. The white box focuses on a warm core eddy about to detach from the Kuroshio, and a pair of drifting buoys is noted on the western and eastern sides. These two drifters pass within a half degree of each other while traveling in opposite directions. Close examination indicates the two buoys are on opposite sides of a saddle point that still connects the main current with the detaching eddy. Thus, the system is able to accurately assimilate the altimeter data and act as a dynamical interpolator. Lastly, SST forecast skill of the system is examined. Table 1 shows the mean error (bias) and root-mean-square-error (RMSE) as a function of forecast length. The bias and RMSE gradually grow with forecast length. The spatial distribution of the mean error is shown in Figure 3 for the analysis time and a 3-day forecast. In hindcast mode, the global HYCOM system has also demonstrated forecast skill on time scales up to a month for the meandering currents and eddies in some regions (not shown).

Table 1. SST error statistics as a function of forecast length from the 1/12° global HYCOM prediction system compared against ~33,000,000 satellite-based observations. The analysis is performed over a year-long hindcast spanning June 2007-May 2008 and is limited to the area between 45°S – 45°N

	Mean error	RMSE
Analysis	-.02	.36
1-day forecast	-.09	.44
2-day forecast	-.14	.52
3-day forecast	-.18	.60
4-day forecast	-.22	.67
5-day forecast	-.26	.72

Impact

A next-generation ocean nowcasting/forecasting system based on 1/12° global HYCOM is running in real-time at the Navy DSRC. It can accurately depict and forecast such features as western boundary currents and sharp ocean fronts, thus providing improved environmental awareness to the Fleet. Other naval applications include optimum track ship routing, search and rescue, anti-submarine warfare and surveillance, tactical planning, and providing boundary conditions for regional and coastal nested model. HPC resources have played a major role in making this state-of-the-art system feasible, beginning with the preliminary development of HYCOM and continuing all the way through its transition as a pre-operational product.

References

Bleck, R., 2002. An oceanic general circulation model framed in hybrid isopycnic-Cartesian coordinates. *Ocean Modelling*, 4, 55-88.

Cummings, J.A., 2005. Operational multivariate ocean data assimilation. *Quart. J. Royal Met. Soc.*, 131, 3583-3604.

Hurlburt, H.E., E.P. Chassignet, J.A. Cummings, A.B. Kara, E.J. Metzger, J.F. Shriver, O.M. Smedstad, A.J. Wallcraft, and C.N. Barron, 2008. Eddy-resolving global ocean prediction. In: Hecht, M., Hasumi, H. (Eds.), Ocean Modeling in an Eddying Regime, Geophysical Monograph 177. *American Geophysical Union*,Washington, DC.

Metzger, E.J., O.M. Smedstad, P. Thoppil, H.E. Hurlburt, A.J. Wallcraft, D.S. Franklin, J.F. Shriver and L.F. Smedstad, 2008. Validation Test Report for Global Ocean Prediction System V3.0 – 1/12° HYCOM/NCODA: Phase I, *NRL Memo. Report*, NRL/MR/7320—08-9148.