

Predicting “Ocean Weather” Using the HYbrid Coordinate Ocean Model (HYCOM)

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Introduction: 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 are typically ~100 km and current speeds can easily exceed 1 ms^{-1} in the Gulf Stream (Atlantic) and Kuroshio (Pacific). Numerical ocean models with sufficiently high horizontal and vertical resolution are needed to depict the 3-D structure with accuracy superior to climatology and/or persistence (i.e. a forecast of no change). The existing two-model operational system, run daily at the Naval Oceanographic Office (NAVOCEANO), is based on the $1/32^\circ$ Navy Layered Ocean Model (NLOM) and the $1/8^\circ$ Navy Coastal Ocean Model (NCOM). Unlike NLOM, NCOM has high vertical resolution, but it has medium range horizontal resolution (15 km at mid-latitudes near 40°N) that is eddy-permitting. The next generation system is based on a single model, the HYbrid Coordinate Ocean Model (HYCOM), that 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 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). It represents the world’s first eddy-resolving global ocean prediction system with both high horizontal and vertical resolution and has been running daily in the operational queues at NAVOCEANO since 22 December 2006. The HYCOM system has been validated against observational data (Metzger et al., 2008) and is scheduled for operational testing in 2009.

Prediction system description: The ocean component of the nowcast/forecast system is 1/12° global HYCOM (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 sigma-levels (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), 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 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.

Real-time results: Where possible, the real-time system is evaluated using independent observations and some examples follow. Figure 1 shows simulated SSH for the Gulf Stream and the Kuroshio current systems. The assimilation of satellite altimeter SSH anomalies is essential to accurately map the circulation in these highly chaotic regions

dominated by 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 into the system, 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), root-mean-square-error (RMSE), skill score (a non-dimensional quantity with perfect skill having a value of 1) and correlation 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. The system has demonstrated forecast skill lasting up to about a month for the meandering currents and eddies in some regions.

Impact: A next generation $1/12^\circ$ global ocean nowcast/forecast system is running in real-time at NAVOCEANO. It is designed to replace an existing nowcast/forecast system and have more than twice as fine grid resolution. It can more accurately depict such features as western boundary currents and sharp ocean fronts, thus providing improved environmental awareness to the Fleet.

References:

- 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.

Table 1: SST error statistics vs. ~33,000,000 MCSST observations				
Analysis between 45°S – 45°N				
	Mean error	RMSE	Skill score	Correlation
Analysis	-.02	.36	.99	1.0
1-day forecast	-.09	.44	.99	1.0
2-day forecast	-.14	.52	.99	.99
3-day forecast	-.18	.60	.98	.99
4-day forecast	-.22	.67	.98	.99
5-day forecast	-.26	.72	.98	.99

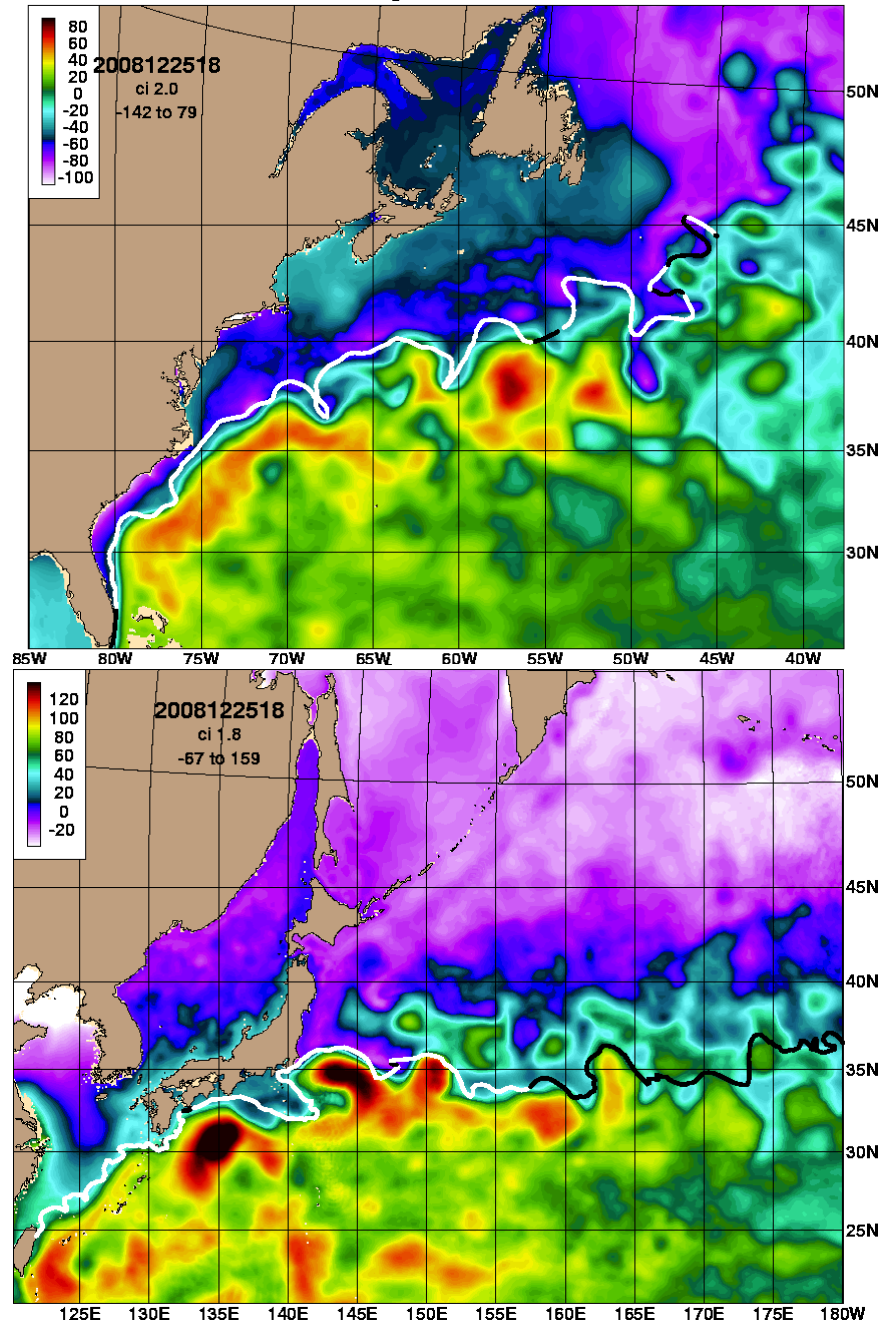


Figure 1: Sea surface height (cm) from the 1/12° global HYCOM/NCODA forecast system for the Gulf Stream in the Atlantic Ocean (top) and the Kuroshio in the Pacific Ocean (bottom) on 22 December 2008. The ribbon of high gradient color shows the location of these western boundary currents; embedded within 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 the Naval Oceanographic Office and overlain on each image. A white (black) line means the IR analysis is based on data less (more) than four days old.

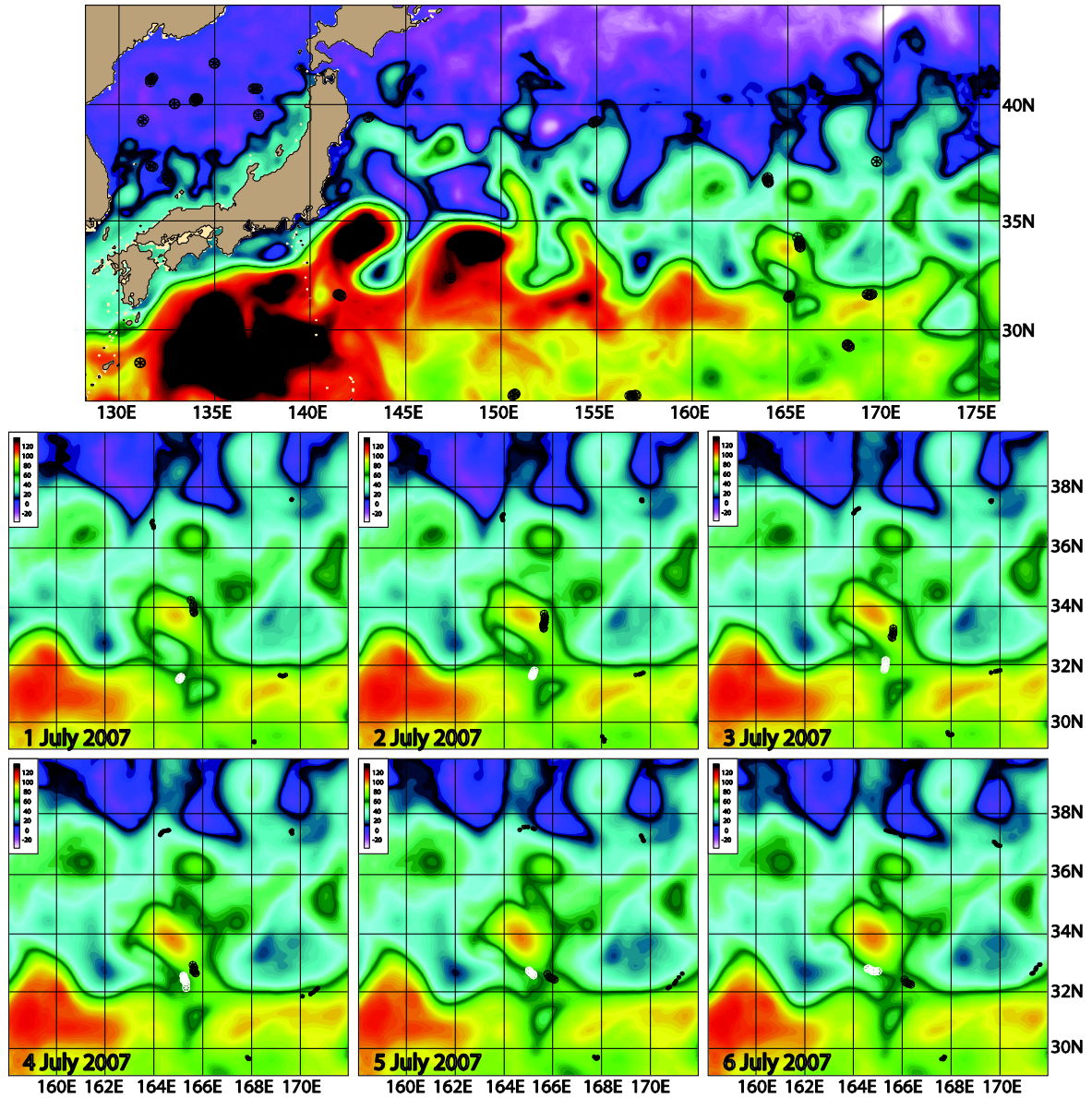


Figure 2: Sea surface height (cm) from the 1/12° global HYCOM/NCODA forecast system for the Kuroshio on 1 July 2007 (top). Drifting buoys tracks over a 1 day time period are overlain on each panel. The white box defines the focused area of the bottom six panels that span the time frame 1-6 July 2007. 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.

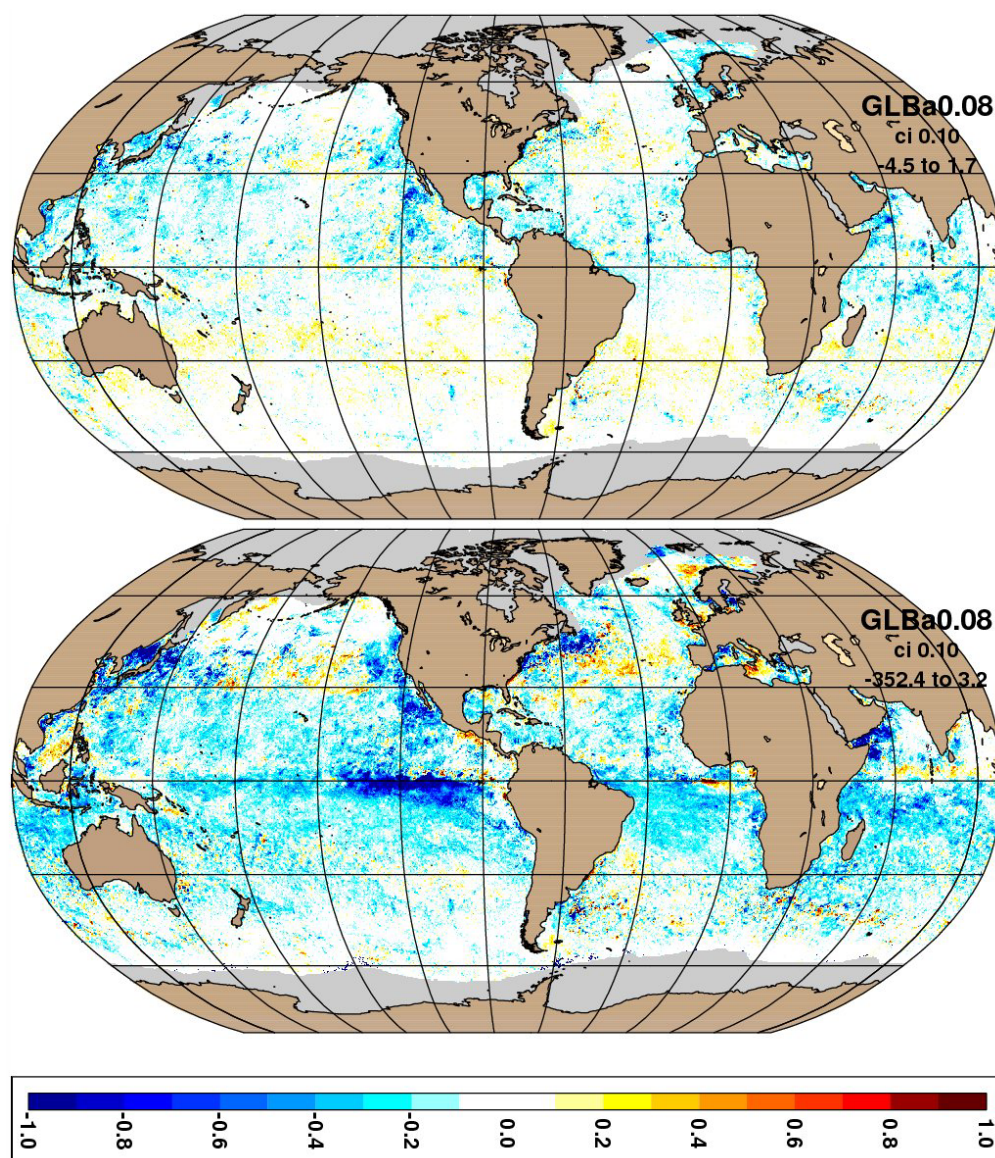


Figure 3: Sea surface temperature (SST) mean error (bias) relative to ~33,000,000 MCSST observations at the analysis time (top) and for a 3-day forecast (bottom). Red (blue) colors indicate simulated SST is warmer (cooler) than observed. Values between $\pm 0.1^{\circ}\text{C}$ are white. The gray area near the poles is an annual average ice coverage mask.