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14. ABSTRACT

This is the first year of a three-year Challenge Project with the principal goal of performing the necessary research and development to prepare to provide real time depiction of the three-dimensional global ocean state at fine resolution (1/25° on the equator, 3.5 km at mid-latitudes, and 2 km in the Arctic). The prediction system won't run in real time until FY12, since this is when the first computer large enough to run it in real time is expected to be available at NAVOCEANO. A major sub-goal of this effort is to test new capabilities in the existing 1/12° global HYbrid Coordinate Ocean Model (HYCOM) nowcast/forecast system and to transition some of these capabilities to NAVOCEANO in the existing 1/12° global system, and others in the 1/25° system. The new capabilities support (1) Increased nowcast and forecast skill, the latter out to 30 days in many deep water regions, including regions of high Navy interest, such as the Western Pacific and the Arabian Sea/ Gulf of Oman, (2) boundary conditions for coastal models in very shallow water (to zero depth with wetting and drying), and (3) external and internal tides, the latter with initial testing at 1/12° but transition to NAVOCEANO only in the 1/25° system (all these will greatly benefit from the increase to 1/25° resolution). At 1/25°, the entire first year will be spent on initial climatologically forced non-assimilative simulations that are necessary before we can start data assimilation hindcasts. At 1/12°, we have started exploring improved model configurations with climatologically forced runs and testing improved data assimilation with hindcast cases.

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Eddy Resolving Global Ocean Prediction

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Abstract

This is the first year of a three-year Challenge Project with the principal goal of performing the necessary research and development (R&D) to prepare to provide real time depiction of the three-dimensional global ocean state at fine resolution ($1/25^\circ$ on the equator, 3.5 km at mid-latitudes, and 2 km in the Arctic). The prediction system won't run in real time until FY12, since this is when the first computer large enough to run it in real time is expected to be available at NAVOCEANO. A major sub-goal of this effort is to test new capabilities in the existing $1/12^\circ$ global Hybrid Coordinate Ocean Model (HYCOM) nowcast/forecast system and to transition some of these capabilities to NAVOCEANO in the existing $1/12^\circ$ global system, and others in the $1/25^\circ$ system. The new capabilities support (1) increased nowcast and forecast skill, the latter out to 30 days in many deep water regions, including regions of high Navy interest, such as the Western Pacific and the Arabian Sea/ Gulf of Oman, (2) boundary conditions for coastal models in very shallow water (to zero depth with wetting and drying), and (3) external and internal tides, the latter with initial testing at $1/12^\circ$ but transition to NAVOCEANO only in the $1/25^\circ$ system (all these will greatly benefit from the increase to $1/25^\circ$ resolution).

At $1/25^\circ$, the entire first year will be spent on initial climatologically forced non-assimilative simulations that are necessary before we can start data assimilation hindcasts. At $1/12^\circ$, we have started exploring improved model configurations with climatologically forced runs and testing improved data assimilation with hindcast cases.

1. Introduction

One important aspect of ocean model design is the choice of the vertical coordinate system. Traditional ocean models use a single coordinate type to represent the vertical, but model comparison exercises performed in Europe (DYNamics of North Atlantic Models -

DYNAMO) (Willebrand et al., 2001) and in the United States (Data Assimilation and Model Evaluation Experiment - DAMÉE) (Chassignet et al., 2000) have shown that none of the three main vertical coordinates then in use (depth [z-levels], density [isopycnal layers], or terrain-following [σ -levels]) could by itself be optimal everywhere in the ocean. The Hybrid Coordinate Ocean Model (HYCOM) (Bleck, 2002) is configured to combine all three of these vertical coordinate types. It is isopycnal in the open, stratified ocean, but uses the layered continuity equation to make a dynamically smooth transition to a terrain-following coordinate in shallow coastal regions, and to z-level coordinates in the mixed layer and/or unstratified seas. The hybrid coordinate extends the geographic range of applicability of traditional isopycnal coordinate circulation 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 is designed to provide a major advance over the existing operational global ocean prediction systems, since it overcomes design limitations of the present systems as well as limitations in vertical and horizontal resolution. The result should be a more streamlined system with improved performance and an extended range of applicability (e.g., the present systems are seriously limited in shallow water and in handling the transition from deep to shallow water).

Global HYCOM with $1/12^\circ$ horizontal resolution at the equator (~ 7 km at mid-latitudes) is the ocean model component of the eddy-resolving operational nowcast/forecast system currently running in real time in the operational queue on the Cray XT5 at the Naval Oceanographic Office (NAVOCEANO). It provides nowcasts and forecasts of the three-dimensional (3D) global ocean environments. HYCOM is coupled to the Los Alamos sea-ice model [CICE] (Hunke and Lipscomb, 2004) via the Earth System Modeling Framework [ESMF] (Hill et al., 2004), although currently only for the Arctic. Coupling between the ocean and ice models more

properly accounts for the momentum, heat and salt fluxes at the ocean/ice interface. The final component of the nowcast/forecast system is the Navy Coupled Ocean Data Assimilation (NCODA) which is a multivariate optimal interpolation scheme that assimilates surface observations from satellites, including altimeter and Multi-Channel Sea Surface Temperature (MCSST) data, sea ice concentration and also profile data such as XBTs (expendable bathythermographs), CTDs (conductivity temperature depth), and Argo floats (Cummings, 2005). By combining these observations via data assimilation and using the dynamical interpolation skill of the model, the 3D ocean state can be accurately nowcast and forecast.

3. Model Setup

The global model is configured on a Mercator grid from 78°S to 47°N, while north of this latitude an Arctic dipole patch is used to avoid the singularity at the pole. The 1/25° equatorial resolution translates to an array size of 9,000×6,595, with 32 hybrid layers in the vertical. HYCOM was initialized using temperature and salinity from the 1/4° Generalized Digital Environmental Model (GDEM3) climatology. In this first year of this project, the majority of the global experiments are non-assimilative and use climatological monthly mean wind and thermal forcing constructed from the second 1.125° European Centre for Medium-Range Weather Forecasts (ECMWF) Re-Analysis (ERA-40) over the 1979–2002 time frame with 6-hourly variability from the Fleet Numerical Meteorology and Oceanography Center (FNMOC) Navy Operational Global Atmospheric Prediction System (NOGAPS) operational model over the period January 2003–January 2004 added to get realistic simulation of the surface mixed layer. In order to keep the evaporation-precipitation budget on track, the model weakly relaxes to the Polar Science Center Hydrographic Climatology sea surface salinity (Steele et al., 2001). Figure 1 compares the sea surface height variability in the Gulf Stream region from identical twin simulations at 1/12° and 1/25° after just three model years with a long track variability from four satellite altimeters. The Gulf Stream greatly benefits from higher resolution and it is already penetrating further with more realistic variability at 1/25°.

4. Assimilative Global HYCOM Evaluations

At 1/12°, our primary focus is on cases that assimilate oceanic data. These start from, and are data-assimilative twins of, an extension of a climatologically forced experiment with interannual wind and thermal forcing from the 2003–2009 3-hourly NOGAPS. Since

December 2006, we have run a nowcast every day, and since February 2007 we perform a nowcast and at least a 3-day forecast every day in real-time. Results are at <http://www7320.nrlssc.navy.mil/GLBhycom1-12/skill.html>.

An important aspect of preparing a new system for potential operational use is to compare it to the comparable existing operational system. In this case, the current operational system is 1/32° near-global Navy Layered Ocean Model (NLOM) (Wallcraft et al., 2003) with 6 layers in the vertical in combination with the 40-level 1/8° global Navy Coastal Ocean Model (NCOM) (Barron et al., 2006; Kara et al., 2006). NLOM is used to assimilate Sea Surface Height (SSH) along altimeter tracks with the model forecast as a first guess for each analysis cycle and to make 30-day ocean weather forecasts. NCOM assimilates steric SSH anomalies from NLOM in the form of synthetic temperature (T) and salinity (S) profiles (Rhodes et al., 2002) and makes 4-day forecasts. This two-model global system requires less computer power than a single global model with both high horizontal and high vertical resolution. Note that these systems measure horizontal resolution at mid-latitudes, so 1/8° NCOM is actually 2.2x coarser than 1/12° HYCOM (~15 km vs. ~7 km at mid-latitudes). The intent is for HYCOM to replace both components of the existing system, and in particular HYCOM will replace NCOM as the provider of boundary conditions for regional and coastal models. In its turn, the 1/25° system will need to demonstrate value added over the 1/12° system as it exists in FY12 and beyond.

The comparisons include: sea surface height variability, vertical profiles of temperature and salinity, sea surface temperature, coastal sea level, and proxies for the acoustical environment. Figure 2 summarizes the results from one such acoustic proxy, Sonic Layer Depth, which is the vertical distance from the surface to the depth of the local sound speed maximum, often but not always at the base of the mixed layer. The percentage of points where HYCOM/NCODA has equal or less absolute error than NCOM is 51% for the whole domain, 48% in the western Pacific and 51% in the Arabian Sea.

5. Plans

At 1/25°, all of FY09 and the majority of FY10 will be spent on initial non-assimilative runs that are necessary before we can start data assimilation hindcasts. First the model will be run ~20 years with climatological atmospheric forcing (10 years in FY09, at least one simulation will include tides) and then extended 1995 to 2002 with 6-hourly inter-annual atmospheric forcing from NOGAPS. The 1995 start date is to make sure we can realistically simulate the very challenging 1997–1998 El

Niño/La Niña, including the onset of El Niño and the large sudden drop in equatorial Pacific SST during the transition to La Niña. Finally a single May 2001 to June 2002 data assimilation hindcast will round out FY10. The 1/12° workload will be a combination of assimilative and non-assimilative cases designed to upgrade the capability of the existing 1/12° nowcast/forecast system and to minimize the number of 1/25° cases we need to run. Several 1/12° cases will include tides and other sub-daily effects.

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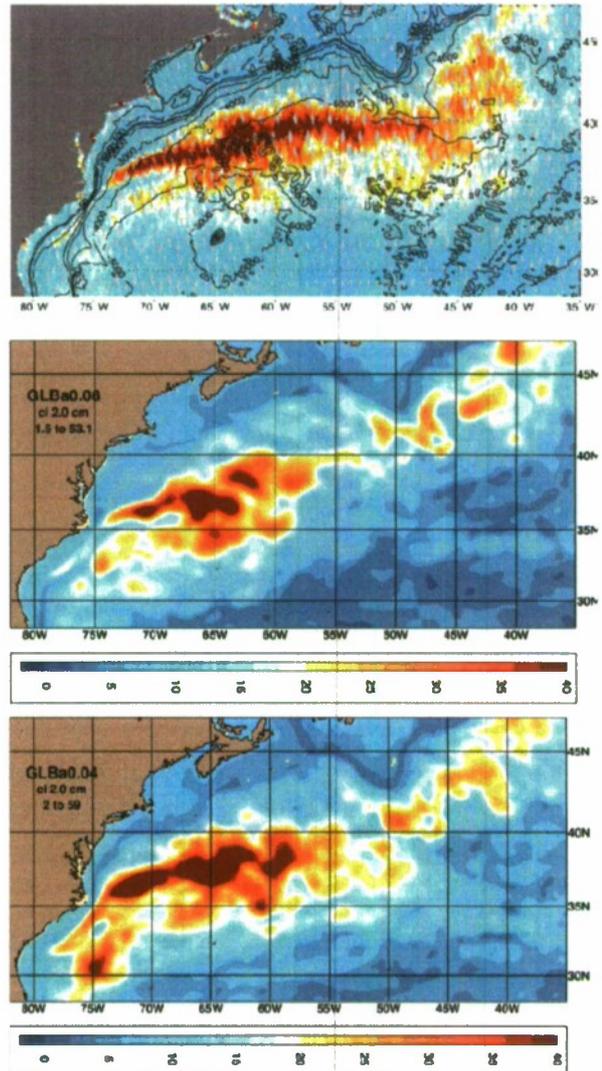


Figure 1. Zooms of the Gulf Stream region, all using the same color scale in cm. (a) Quasi-contemporaneous along-track RMS SSH variability from satellite altimeter data in four orbits overlaid on topographic contours (depth in m). The tracks are overlaid in the following order from top to bottom: (1) Envisat, (2) GFO, (3) Jason-1, and (4) Topex Interleaved. (b,c) RMS SSH variability over model year 3 from non-assimilative (b) 1/12° and (c) 1/25° global HYCOM simulations.

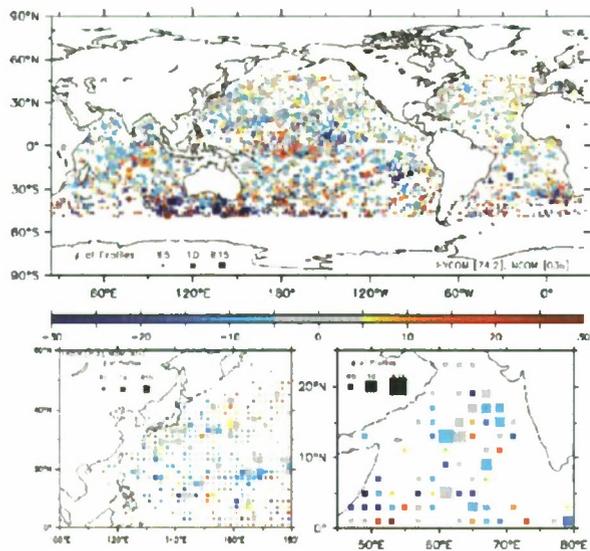


Figure 2. Sonic Layer Depth (SLD) relative Median Absolute Error (MdAE)) in meters for the whole domain (top) using 17,263 unassimilated profiles, western Pacific Ocean (bottom left) using 2,218 unassimilated profiles and the Arabian Sea (bottom right) using 275 unassimilated profiles. Positive (negative) values indicate HYCOM/NCODA (NCOM) has lower absolute error. The analysis in the top panel is limited to $\pm 50^\circ$ latitude. MdAE is less than 5 m in those boxes colored gray. The data are averaged over 2° bins and the number of profiles within each bin is indicated by the size of each individual square as denoted by the legend within each plot.