HYCOM Coastal Ocean Hindcasts and Predictions: Impact of Nesting in HYCOM GODAE Assimilative Hindcasts

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LONG-TERM GOALS

The overarching goal is to improve our capability to map, understand, and predict changes in currents and water properties in the coastal ocean. This capability is important for a wide range of purposes, including naval operations, search and rescue operations, commercial marine operations (including the influence of ocean currents on shipping and oil rigs), prediction of coastal hazards such as storm surge, prediction of pollution dispersion, and the influence of currents and water properties on coastal fisheries and ecosystems. Providing real-time (nowcast) and future (forecast) coastal ocean fields for these purposes require a coastal ocean nowcast/forecast system that consists of several components:

1. a high-quality ocean general circulation model;
2. accurate surface flux (atmospheric forcing) fields to drive the ocean model;
3. accurate estimates of coastal ocean fields at the start of a model run and along the lateral boundaries of the coastal domain during model runs;
4. accurate estimates of freshwater input from rivers and estuaries; and
5. high-quality ocean observations.

The observations are necessary to provide the accurate initial and boundary fields required by component (3) and to evaluate the performance of the nowcast/forecast system. The central focus of this project is component (3), specifically to quantify and understand the impact of initial and boundary fields on coastal ocean nowcasts and forecasts, and to provide feedback that will motivate improvements in generating these fields.

Although the coastal ocean is strongly influenced by surface atmospheric forcing and coastal freshwater runoff, offshore ocean variability exerts a very significant influence in many regions due to a wide range of processes such as basin-scale climate variability, boundary current meanders, and offshore ocean eddies. To accurately represent the influence of this offshore variability on a coastal ocean model, the model must be nested within fields that accurately represent (1) the initial state of the coastal ocean throughout the model domain and (2) currents and water properties along the nested model boundaries with the adjacent ocean. We are evaluating initial and boundary fields provided by a nowcast/forecast system based on the HYbrid Coordinate Ocean Model (HYCOM) developed at the Naval Research Laboratory (NRL-Stennis) as part of the Global Ocean Data Assimilation Experiment (GODAE). Nowcast/forecast systems provide relatively accurate ocean fields by combining ocean observations and ocean model output using data assimilation. The influence of the initial and boundary fields on the performance of a coastal model are being thoroughly evaluated using HYCOM as the nested coastal model. Results are being communicated to NRL to guide improvement strategies for their nowcast/forecast system. The overall regional focus of this project encompasses the coastal northern and eastern Gulf of Mexico along with the Florida Straits and Florida Bay, which represent a broad range of shelf geometries, river runoff, seasonal atmospheric forcing changes, and both weak and strong offshore forcing. Three regions are emphasized: the South Florida Coastal Region (SoFLA), including the Florida Straits, Florida Keys, Florida Bay, and the adjacent southwest Florida shelf; the West Florida Shelf (WFS); and the Northern Gulf Coastal Region (NGCR).

Although our central focus is on component (3), we also consider the other four components of the coastal nowcast/forecast system. We are striving to improve ocean model performance, evaluate model sensitivity to different atmospheric forcing products, study sensitivity to river runoff, and assess the adequacy of available coastal ocean observations. Coastal ocean simulations are also being analyzed to improve our scientific understanding of ocean variability observed in our region of interest.

OBJECTIVES

The objectives are split into two categories: operational and scientific. Operational objectives include:

1. determining how changes in the initial and boundary conditions provided by nowcast/forecast products (e.g. resolution, free-running versus assimilative, assimilation methodology) influence the capability of nested models to simulate and predict the coastal ocean environment;
2. evaluating the coastal hindcasts and predictions against observations that include existing elements of the Coastal Ocean Observing System (e.g. SEACOOS, GCOOS);
3. identifying the most useful observations for evaluating and improving coastal ocean models that should be maintained as part of a coastal observation network;
4. evaluating HYCOM development as a coastal ocean model against observations and against simulations by other model types (ROMS and POM); and
5. offering feedback to guide improvement in the nowcast/forecast products that provide initial and boundary information to nested coastal (and regional) models.

Specific scientific objectives include:

1. determining the impact of offshore currents (Loop Current and eddies, Florida Current; basin-scale wind-driven gyre circulation) on coastal ocean circulation;
2. determining the impact of higher-frequency offshore variability (rectification), if any, on the annual cycle of coastal circulation;
3. studying the impact of vertical mixing and friction (including the surface and bottom boundary layers) on simulated coastal circulation, taking advantage of the multiple vertical mixing choices (Halliwell, 2004) in HYCOM;
4. quantifying and understanding shelf-slope exchange processes;
5. studying the dynamics of transient eddies, including the Tortugas eddy in the Florida Straits in the SoFLA domain;
6. determining the impact of Everglades runoff in the WFS and SoFLA domains;
7. understanding impact of the Mississippi river plume locally in the NCGR domain and remotely in the WFS and SoFLA domains; and
8. studying the coastal ocean response to hurricanes.

We are providing physical fields from the West Florida Shelf and the South Florida domains to other researchers interested in biochemical processes such as larval recruitment, red tide, etc (e.g., Olascoaga *et al.*, 2006).. We are also providing SoFLA fields to scientists and managers associated with the Florida Bay and Florida Keys Feasibility Study of the Comprehensive Everglades Restoration Project.

APPROACH AND WORK PLAN

The initial effort involves running and evaluating nested coastal ocean hindcasts, then using all available ocean observations to evaluate coastal model performance. Sensitivity to initial and boundary conditions is now being assessed by nesting the coastal models in fields provided by three products: the original NRL experimental Atlantic Ocean product that used optimum interpolation to assimilate ocean observations into model fields (HYCOM-OI), the next-generation NRL product being tested within a Gulf of Mexico domain that uses multi-variate optimum interpolation to assimilate all available ocean observations (HYCOM-NCODA), and a free-running Gulf of Mexico simulation where no observations are assimilated (HYCOM-FREE). Other nowcast-forecast products generated using more advanced techniques to assimilate ocean observations will be evaluated as they become available. For evaluation, these runs are being compared to each other, to the fields that provided initial and boundary conditions, and to in-situ observations. Evaluation of coastal models will also determine how often boundary condition fields should be provided (daily or sub-daily), where the boundaries of the nested domains should be situated, and how wide the boundary zones should be. Model evaluation in each domain will take advantage of existing observing system programs. For the SoFLA domain, this includes coastal radar (WERA) and an extensive observational network centered in Florida Bay supported by NOAA for the Everglades Restoration Project. For the WFS domain, this includes the extensive observational network maintained by the University of South Florida by R. Weisberg. For NGCR, this includes observations acquired by NRL and other regional research institutions. The most optimal runs identified by the evaluation effort will be used to conduct studies that address the scientific objectives listed above. The initial evaluation and scientific analysis will focus on 2004-2005. Longer time intervals will be analyzed later to study the annual cycle and interannual variability. Following evaluation of coastal ocean hindcasts, the sensitivity of coastal ocean forecasts to different initial/boundary products will be evaluated. The evolving boundary conditions during coastal forecast runs will be provided by forecasts produced by NRL using their nowcast/forecast systems.

WORK COMPLETED

The initial work naturally emphasized setting up the nowcast/forecast systems and generating the ocean fields within which the coastal models are being nested. The original NRL HYCOM-OI assimilation system routinely produced ocean fields during 2006. Initial development of the next-generation HYCOM-NCODA system was completed during 2006. For its initial evaluation, this new system was run from September 2003 to the present within a new 0.04° Gulf of Mexico domain. Also, a free-running simulation (HYCOM-FREE) was run for the same time interval in the same Gulf of Mexico domain. These three products are the focus of our initial evaluation effort, which will be conducted for a two-year time interval (2004-2005).

While waiting for these outer model runs, progress was made in setting up and running HYCOM in the coastal domains. For the SoFLA domain, an initial experiment spanning 1999-2002 nested in an old free-running model simulation was evaluated to provide benchmark results for the evaluation of the three products during 2004-2005. A new SoFLA domain was set up for the 2004-2005 evaluation effort by extending the northern and eastern boundaries to allow a better representation of coastal to deep sea interactions. Meanwhile, HYCOM was configured to run in the WFS domain using the same curvilinear horizontal grid used at the University of South Florida to run other model types. Coastal simulations in the SoFLA and WFS domains using the three choices for initial/boundary conditions are now underway and will be completed during January 2007. Setup of the third (NGCR) coastal domain has just been completed and simulations within this domain will commence shortly. Preliminary results were presented during November 2006 at the HYCOM Principal Investigators meeting.

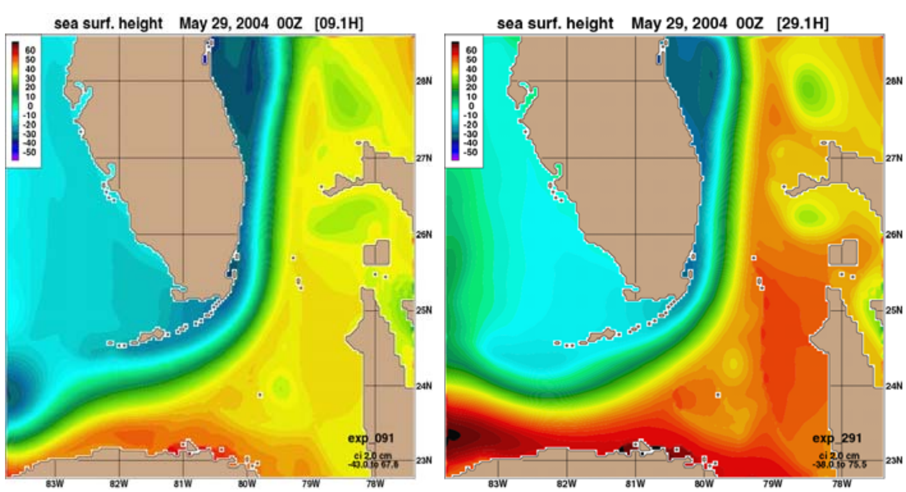

Figure 1. SoFLA domain sea surface height (SSH) on 5/29/04 from twin experiments with initial and boundary conditions from the HYCOM-FREE (left) and HYCOM-NCODA Gulf of Mexico simulations (right).

RESULTS

Initial 2004-2005 results in the SoFLA domain demonstrate that the nesting procedure performed very well, as currents and water properties in the vicinity of the open boundaries exhibited a smooth transition between the outer and nested domains. Preliminary analysis of sea surface height (SSH) fields for the simulations with boundary conditions obtained from HYCOM-FREE and HYCOM-NCODA Gulf of Mexico simulations revealed noticeable changes in the location of the Loop Current and Florida Current fronts along with the associated eddies (Figure 1). Comparison with satellite-derived sea surface temperature (SST) and ocean color maps (not shown) demonstrate that the data assimilation used in HYCOM-NCODA produced initial/boundary conditions that more accurately reproduced the location of these ocean features.

At the University of South Florida, a test WFS simulation for 2005 using the ROMS (Regional Ocean Modeling System) coastal model nested within the HYCOM-OI product was evaluated against water column currents from Acoustic Doppler Current Profiler measurements, surface currents from high-frequency radar measurements, and water column temperature-salinity from profiling floats. The coastal simulation showed reasonable agreement with the ocean observations. In particular the model was able to simulate the strong vertical temperature-salinity stratification observed prior to Hurricane Katrina that was associated with a benthic die-off due to the trapping of red tide organisms (K. brevis) beneath the pycnocline. The ROMS simulation performed better when nested in the HYCOM-OI product compared to nesting ROMS within climatological ocean fields.

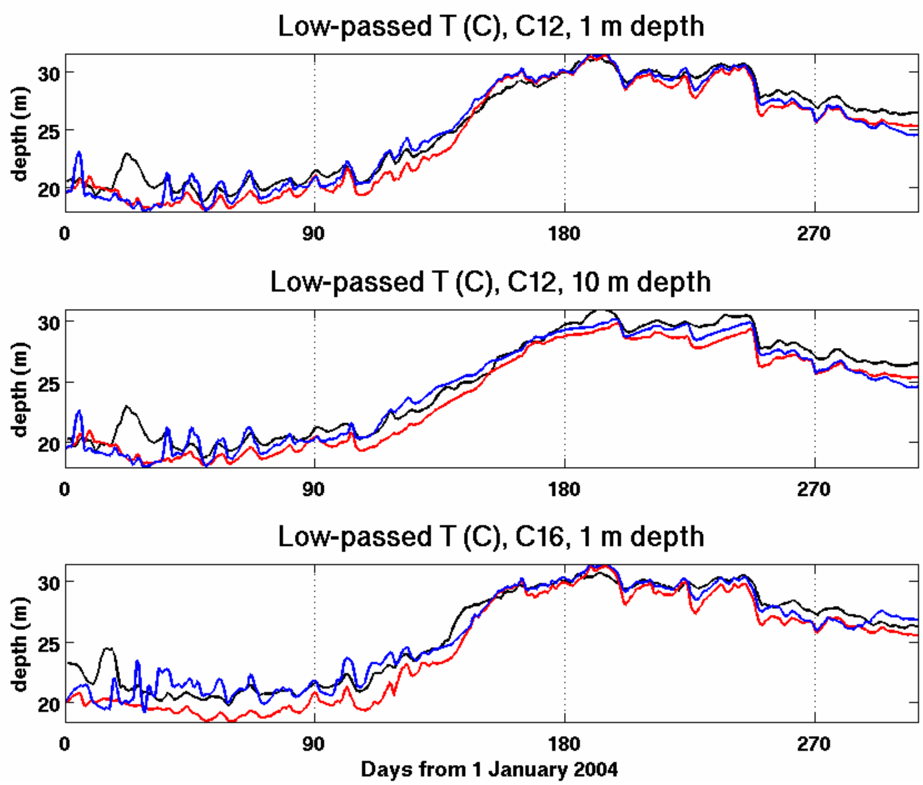

Figure 2. Time series of temperature over the first 10 months of 2004 at two locations over the West Florida Shelf west of Tampa Bay. Time series are shown for two depths at station C12 (middle continental shelf) and at one depth at station C16 (outer shelf). Black lines are observed

temperature, red lines are simulated temperature using HYCOM-FREE initial/boundary conditions, and blue lines are simulated temperature using HYCOM-NCODA initial/boundary conditions.

At the University of Miami, the HYCOM coastal model runs on the same model grid used by USF. Initial comparison of observed and simulated temperature time series at two locations in the WFS domain (Figure 2) demonstrate that the error in simulated temperature as measured by the root-mean-square difference between time series decreased by 15 to 30% when the more accurate initial and boundary conditions provided by HYCOM-NCODA were used instead of fields provided by HYCOM-FREE. This result is encouraging, and these and other detailed comparisons between observed temperature, salinity, and current velocity will be performed in different regions to understand the impact of changing initial and boundary conditions and determining the best source of these ocean fields for nested coastal ocean simulations.

IMPACT/APPLICATIONS

National Security

This project will improve the capability of HYCOM to hindcast and forecast currents and water properties in the coastal ocean. HYCOM will be transitioned to the U. S. Navy for operational use by FY2008, and will be used to provide information on ocean currents and water properties for naval operations.

Quality of Life

Improved performance of coastal ocean models will improve our capabilities in commercial marine operations (including the influence of ocean currents on shipping and oil rigs), storm surge prediction, prediction of pollution dispersion, studies of coastal fisheries and ecosystems, and providing ocean currents for search and rescue operations.

Science Education and Communication

As part of this project and the HYCOM-GODAE project, we are making research results available on the internet – see http://hycom.rsmas.miami.edu. These projects are supporting graduate students.

TRANSITIONS

National Security

The ocean model used in this study (HYCOM) will become the operational ocean model used by the U. S. Navy by FY2008. The work performed under this project will lead to model improvements that will positively impact Navy operations.

RELATED PROJECTS

The HYCOM-GODAE product is being developed as part of a NOPP project funded by ONR and NOAA to develop a global ocean data assimilation system that will be used to both nowcast and forecast the state of the global ocean. This project will provide information that will be used to improve the HYCOM-GODAE product.

PUBLICATIONS

Olascoaga, M. J., I. I. Rypina, M. G. Brown, F. J. Beron-Vera, H. Kocak, L. E. Brand, G. R. Halliwell, and L. K. Shay, 2006: Persistent transport barrier on the West Florida Shelf. *Geophys. Res. Lett.*, in press.