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 determine how simulations and forecasts of currents and water properties in the coastal ocean, and the scientific results obtained from them, are influenced by the initial and boundary conditions provided to nested coastal ocean models. In addition to surface atmospheric forcing and coastal freshwater runoff, the coastal ocean is influenced by offshore ocean variability resulting from processes ranging from basin-scale wind-driven gyre and thermohaline circulation down to regional and local circulation associated with boundary currents and eddies. To accurately represent the offshore ocean influence, the coastal model must be nested within fields that accurately represent (1) the initial state of the ocean throughout the model domain and (2) currents and water properties at the nested model boundaries during the model run. We specifically evaluate the HYCOM (HYbrid Coordinate Ocean Model) data assimilation products developed as part of the Global Ocean Data Assimilation Experiment (GODAE) for providing these fields. Coastal model evaluation is being performed over a range of environments to provide feedback that will guide improvements to the HYCOM-GODAE products. The overall regional focus encompasses the coastal northern and eastern Gulf of Mexico through the Florida Straits, which represent a broad range of shelf geometries, river runoff, seasonal atmospheric forcing, and offshore forcing. Three regions are emphasized: (1) the West Florida Shelf (WFS); (2) the South Florida Coastal Region (SoFLA), including the Florida Straits, the Florida Keys and Atlantic Keys shelf, Florida Bay, and the adjacent southwest Florida shelf; and (3) the coastal northern Gulf of Mexico (NGoM). This project focuses only on downscaling open-ocean variability to the coastal ocean (one way nesting).

OBJECTIVES

Specific operational objectives include:

1. determining how changes in the initial and boundary conditions provided by HYCOM-GODAE products (e.g. resolution, free-running versus assimilative, assimilation methodology) influence the capability of nested models to hindcast 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. providing feedback that will improve the HYCOM GODAE products that provide initial and boundary information to nested coastal (and regional) models.

Specific scientific objectives in the three coastal domains include:

6. determining the impact of offshore currents (Loop Current and eddies, Florida Current; basin-scale wind-driven gyre circulation) on coastal ocean circulation (all three domains);
7. determining the impact of higher-frequency offshore variability (rectification), if any, on the annual cycle of coastal circulation (all domains);
8. studying the impact of vertical mixing and friction (including the surface and bottom boundary layers) on coastal circulation, taking advantage of the multiple vertical mixing choices (Halliwell, 2004) in HYCOM (all domains);
9. quantifying and understanding shelf-slope exchange processes (all domains);
10. studying the dynamics of transient eddies, including the Tortugas eddy, in the Florida Straits (SoFLA domain);
11. studying circulation and nutrient transport in South Florida coastal seas, emphasizing ecologically important areas of Florida Bay and the Florida Keys influenced by Everglades runoff in support of the Comprehensive Everglades Restoration Project (SoFLA domain);
12. understanding impact of the Mississippi river plume (locally in the NGoM, remotely in the WFS and SoFLA domains); and

13. studying the coastal ocean response to hurricanes (all domains).

APPROACH

Each of the three coastal modeling efforts are conducting free-running nested ocean hindcasts, and evaluating them against all available in-situ observations. Sensitivity to initial and boundary conditions are being assessed by nesting free-running coastal ocean models within different outer model products provided by the evolving HYCOM nowcast-forecast system, then comparing simulated fields to each other, to the outer model fields, and to in-situ observations. Evaluation of coastal hindcasts is now underway, and evaluation of forecast runs is planned during the upcoming year, taking advantage of existing ocean observing systems. 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 and colleagues. For NGoM, this includes observations acquired by NRL and other regional research institutions. The most optimal runs identified by the evaluation effort will be used to address the scientific objectives listed above. The initial evaluation and scientific analysis is focusing on years 2004 and 2005.

WORK COMPLETED

Three HYCOM-based outer model analysis products that use data assimilation to improve realism are now available for evaluation: (1) the original Atlantic Ocean optimum interpolation (OI) system where sea surface height anomalies measured by satellite altimetry are assimilated, (2) the initial test of the new NCODA assimilation system (Cummings, 2005) conducted within the GoM and nested within fields derived from HYCOM climatological Atlantic simulations, and (3) the initial global NCODA run. To assess how the improved realism of offshore ocean forcing provided by these products influences our coastal simulations, the models have also been nested in two additional products: monthly climatology and a free-running ocean simulation where the locations of offshore eddies and boundary currents were unconstrained by data assimilation.

For the West Florida Shelf domain, a set of experiments has been completed at RSMAS to document sensitivity of nested free-running HYCOM simulations to initial and boundary conditions provided by the three data-assimilative HYCOM products, and also provided by climatology and the free-running model. Before performing this set of experiments, a preliminary set of experiments was run to determine how far offshore the coastal model boundary should be situated from the continental shelf for optimal performance of the coastal model, and also to determine structure of the vertical coordinates over the continental shelf and slope that should be used in HYCOM coastal ocean simulations. At the University of South Florida, a regional ROMS model of the West Florida Shelf has also been nested in the HYCOM outer models. Results and visualizations from this ROMS modeling effort are updated daily and are available at http://ocgmod1.marine.usf.edu/WFS, and also at http://ocgweb.marine.usf.edu.

The set of experiments in the regional SoFLA domain to date have been nested in two of the three HYCOM data-assimilative products (Atlantic OI and GoM NCODA) along with the free-running GoM simulation. The experiments have also focused on different atmospheric forcing datasets, different river plume parameterizations (line source, point sources, variable total discharge), and different vertical resolution. A new high resolution (~900 m) nest (FKEYS, 83.4 to 79.0°W, 22.8°N to 26.1°N) has been set-up within the SoFLA domain with the important Shark river runoff from USGS prescribed as a line source of fresh water input along the Ten Thousand Island coastline. A simulation for 2004-2005 has been completed and analysis of results is under way. The goal is to study hindcasts during periods when data exist, in particular the WERA high-frequency surface current measurements (http://iwave.rsmas.miami.edu/wera), so that the model results can be evaluated against high-quality observations.

The realistic NGoM domain covers the coastal northern Gulf of Mexico (82.8^0W to 95^0W and 28^0N to 30.5^0N) at a resolution of ~1.8 km. A constant Mississippi river discharge of 13,000 m^3/s is applied and equally distributed over 3 passes (Southwest Pass, South Pass, Pass a Loutre). In the initial test experiment, no other external forcing was imposed and open boundary conditions excluded any influence from the Loop Current. Realistic nested experiments will commence very soon.

RESULTS

The analyses of how the information provided by the outer model impacts coastal ocean simulations demonstrates a significant impact for some processes, but not for other processes. The West Florida Shelf simulations performed at RSMAS demonstrate that currents over the inner half of the continental shelf respond to changes in the coastal wind field and are not significantly influenced by the offshore ocean variability provided by the outer model. Offshore ocean variability exerts a much greater influence over the outer half of the shelf and over the continental slope. Both the nested HYCOM simulations performed at RSMAS and the nested ROMS simulations performed at the University of South Florida demonstrate that coastal simulations are improved by nesting in a realistic ocean data-assimilative model compared to climatology. These results for both HYCOM and ROMS are obtained by comparing model currents to observations of currents made by the University of South Florida. These observations include acoustic Doppler current profiler moorings at several locations, and surface current maps obtained by high-frequency radar (CODAR) observations. Two publications are in preparation describing the RSMAS HYCOM results. One focuses on determining the optimal choice of vertical coordinates over the continental shelf and slope, and the second evaluates the impact of the different outer model choices (including climatology) on the West Florida Shelf simulations. The second paper will be submitted mid-January 2008 to a special issue of the journal *Ocean Dynamics* that will feature papers from a group of projects that are evaluating the influence of outer models on coastal simulations in many regions around the world. The PI (G. Halliwell) has agreed to be a guest editor for this volume. Results from the ROMS evaluation at USF are presented in Barth *et al.* (2007).

In the SoFLA domain, the chosen outer model had little or no influence on wind-driven current fluctuations, as was observed on the inner half of the West Florida Shelf. However, the outer model choice did have a significant positive impact on correctly reproducing the path of the Florida Current and associated eddies through the Straits of Florida. Since the eddies associated with Florida Current path fluctuations travel from southwest to northeast through the Straits of Florida, these features can only enter the domain of the nested model if it is correctly provided by the outer model. This is not possible when the SoFLA model is nested within climatology or a free-running model, neither of which are capable of correctly representing the location of ocean eddies and the Florida Current path. This success is important because the eddies passing through the Florida Straits to the north of the Florida Current strongly influence the recruitment and abundance of important species such as the Florida Lobster (Sponaugle *et al.*, 2005). It is also necessary to nest within an accurate outer model if the nested model is to produce the correct transport carried by the Florida Current. That is because this transport is determined by the basin-wide wind-driven gyre circulation and the Atlantic Meridional Overturning Circulation, and the outer model must provide this information to the SoFLA model. This has been verified by comparing transports simulated by SoFLA HYCOM nested in different products to transports estimated from electromagnetic cable measurements.

FKEYS simulations nested within SOFLA (which is itself nested within GoM-NCODA) are being used in conjunction with WERA surface current measurements to study eddy variability in the Florida Straits, especially the small-scale eddy variability north of the Florida Current that is critically important for species recruitment. One instance where the HYCOM FKEYS simulation produces an eddy coincident with one observed in WERA maps is presented in Figure 1. This correspondence is important because we can then use the model to understand the physical processes responsible for the formation and propagation of this and other eddies. An investigation is now being conducted to determine if this eddy was provided by the outer model and entered the western boundary of the FKEYS domain, or if it was forced within the FKEYS domain.

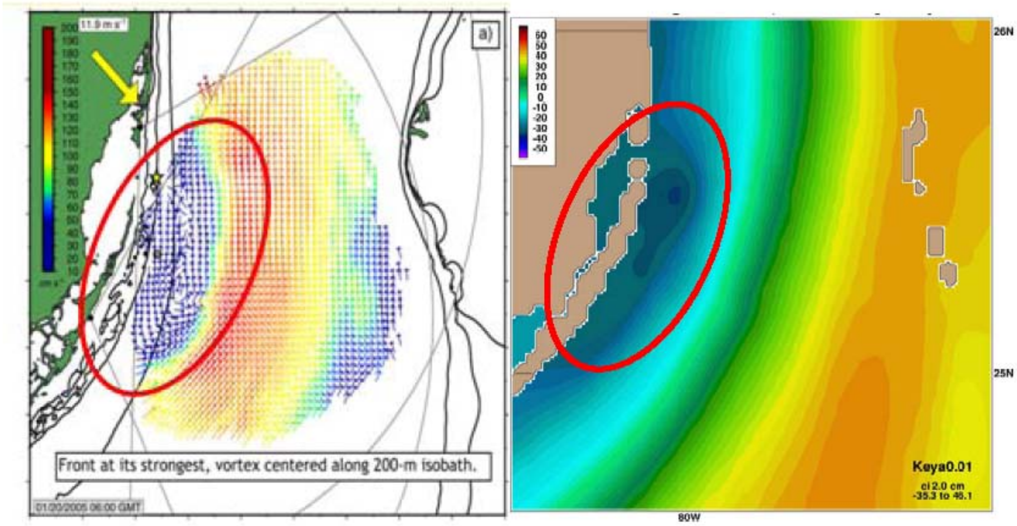

Figure 1. WERA surface current map (left) and HYCOM FKEYS domain sea surface height (SSH) (right) on 20 January 2005. Surface currents flow counterclockwise around the SSH depression (eddy) off Biscayne Bay and thus agree with the radar measurements

IMPACT/APPLICATIONS

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.

Economic Development

Improvement in our capability to model physical variability of the coastal ocean will impact commercial marine operations, such as the impact of ocean currents on marine transportation and on oil rigs.

Quality of Life

Improved capabilities in modeling physical variability in the coastal ocean will be very important for studying the response of coastal ecosystems and fisheries to changes in the ocean, and also for studying pollution dispersal and conducting search and rescue operations.

RELATED PROJECTS

The SoFLA study is also part of the environmental monitoring effort being conducted as part of the Comprehensive Everglades Restoration Project (CERP). The nested SoFLA model is providing the offshore boundary conditions for the Florida Bay modeling team within CERP. At the University of South Florida, a complementary project was initiated for the Cariaco Basin off of Venezuela where a high resolution ROMS model was nested in HYCOM. This project will also be used to evaluate the initial/boundary conditions provided by the HYCOM-GODAE products. V. Kourafalou (PI) leads the Hydrodynamic Modeling project of an integrated, multi-task UM/RSMAS and TAMU effort for integrated ecosystem management and prediction in the Caribbean Sea and Gulf of Mexico. In collaboration with G. Halliwell (co-PI), the Wider Caribbean Region model has been set up and nested within the global HYCOM. V. Kourafalou (PI) and G. Halliwell (co-PI) have a NOAA funded project that is connected to the Northern Gulf of Mexico Cooperative Institute. They will use the NGoM-HYCOM domain to develop a framework for Observing System Simulation Experiments (OSSE's, Atlas 1985) that will be utilized to design optimal observing systems in the NGoM domain. Through an NSF ancillary project (V. Kourafalou, co-PI with S. Sponaugle), the FKEYS-HYCOM is being coupled with the ecological population connectivity BOLTS model (Biophysical Larval Transport System). The coupled model will be used for the study of small eddy variability in the Florida Current and for biophysical simulations of larval transport, taking into account not only the physical transport of larvae, but also the interaction of factors influencing larval survival, habitat selection and condition at settlement.

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