A Community Terrain-Following Ocean Modeling System (ROMS)

PI: Hernan G. Arango
Department of Marine and Coastal Sciences, Rutgers
The State University of New Jersey
71 Dudley Road
New Brunswick, NJ 08901-8521, USA
Phone: (848) 932-3368   Fax: (732) 932-6520   email: arango@marine.rutgers.edu

Award Number: N00014-15-1-2482
http://www.myroms.org

LONG-TERM GOALS

The long-term technical goal is to develop and maintain a Regional Ocean Modeling System (ROMS) for high-resolution scientific and operational applications. Our aim is to produce an open-source, terrain-following, ocean community model for regional nowcasting and forecasting that includes advanced data assimilation, ensemble prediction, and analysis tools for adaptive sampling and circulation dynamics/stability/sensitivity, which is highly relevant to ONR objectives. This project will improve the ocean modeling capabilities of the U.S. Navy for relocatable, coastal, coupled atmosphere-ocean forecasting applications.

OBJECTIVES

The main objectives of this project are:

- To develop and test a robust ocean modeling framework for relocatable coastal ocean prediction applications.
- To develop algorithms and tools for improving U.S. Navy coupled atmosphere-ocean forecasting capabilities.
- To develop advanced 4-dimension Variational (4D-Var) data assimilation capabilities and analysis algorithms for observation sensitivity, observation impact, adaptive sampling, and forecast errors and uncertainties.
- To develop adjoint-based ocean prediction analysis tools similar to those available in Numerical Weather Prediction (NWP) for the atmosphere for circulation stability, sensitivity analysis, and ensemble prediction.
- To develop multiple grid nesting capabilities to resolve complex geographical regions and circulation regimes.
- To extend 4D-Var data assimilation over multiple nested grids.

- To provide the ocean modeling community with the current state-of-the-art knowledge in dynamics, numerical schemes, and computational algorithms technology. ROMS is freely distributed (www.myroms.org) to the Earth's modeling community and has thousands of users worldwide.
- To engage the ocean modeling community by organizing annual scientific workshops and training.

APPROACH

As part of this project, four major research tasks are proposed:

Task 1: Development of nested 4D-Var algorithms.

Task 2: Maintain, upgrade and further develop the adjoint-based algorithms.

Task 3: Improve and update nonlinear model algorithms.

Task 4: Improve and expand documentation. Hold training and user workshops.

WORK COMPLETED

The project is still in its early stages but we have concentrated on **Tasks 2** and **3**.
In collaboration with Prof. A. Moore (University of California, Santa Cruz), we have updated and improved the ROMS 4D-Var algorithms. We updated the algorithm that models the background error covariance to be more efficient and corrected critical bugs. The Restricted B-preconditioned Conjugate Gradient (RBCG) solver (Gürol *et al.*, 2014) was updated to work over multiple outer-loops. The RBCG solver is used in the dual 4D-Var algorithms: *(i)* Physical-space Statistical Analysis System (PSAS) (Cohn *et al.*, 1998) and *(ii)* Indirect representer method (Egbert *et al.*, 1994). The extensive update to the 4D-Var algorithms will be released to the user community in the near future.

Several bugs in the multiple grid nesting algorithms of the nonlinear model were fixed and released to the user community. Originally, for stability, several artificial constraints were imposed to the one-way nesting algorithm to suppress losing or gaining volume and mass. These artificial constraints were removed after fixing crucial bugs in the mass conservation algorithm. Currently, both one- and two-way nesting are very stable and produce similar solutions. Recall that in refinement applications, the one-way interaction has no effect whatsoever on the coarser donor grid because there is no feed back of information. Due to its different spatial and temporal resolutions, the finer grid better resolves the physical phenomena at smaller scales. The averaging of a finer grid solution to update the coarse grid values (fine to coarse) in two-way nesting keeps both solutions in line with each other.

RESULTS

Several complex realistic nested applications for the U.S. East Coast have been configured to evaluate the two-way nesting algorithms as illustrated in Figure 1. The coarser DOPPIO grid-**a** with an averaged resolution of 7km is the donor to the Hudson Canyon grid-**b** and the Chesapeake-Delaware Bays grid-**d**. The refinement ratio is 1:3 for grid-**b** and 1:5 for grid-**d**. The refined grid-**c** is centered at the PIONEER data array and has a 1:3 refinement ratio from grid-**b**.

Currently, we are evaluating two-way nested solutions for grid-**a** and grid-**b**. The model is initialized from DOPPIO operational forecasts on 1-Jan-2014 and run to 31-Dec-2014. The open boundary conditions for DOPPIO (grid-**a**) are derived from Mercator Ocean Forecasts. Figure 2 shows the surface temperature and surface salinity daily averages for 31-Jan-2014. Similarly, Figure 3 shows the sea surface height averaged solution for 31-Jan-2014. The refined grid-**b** solution is overlaid on top of the coarse grid-**a** solution. This solution is very stable for one-year length of the simulation. It illustrates the robustness of ROMS nesting strategy, which evaluates the full governing equation in the contact areas between the nested grids. Multiple grid nesting is an efficient way to resolve bathymetry and dynamics between open-ocean and coastal regions.

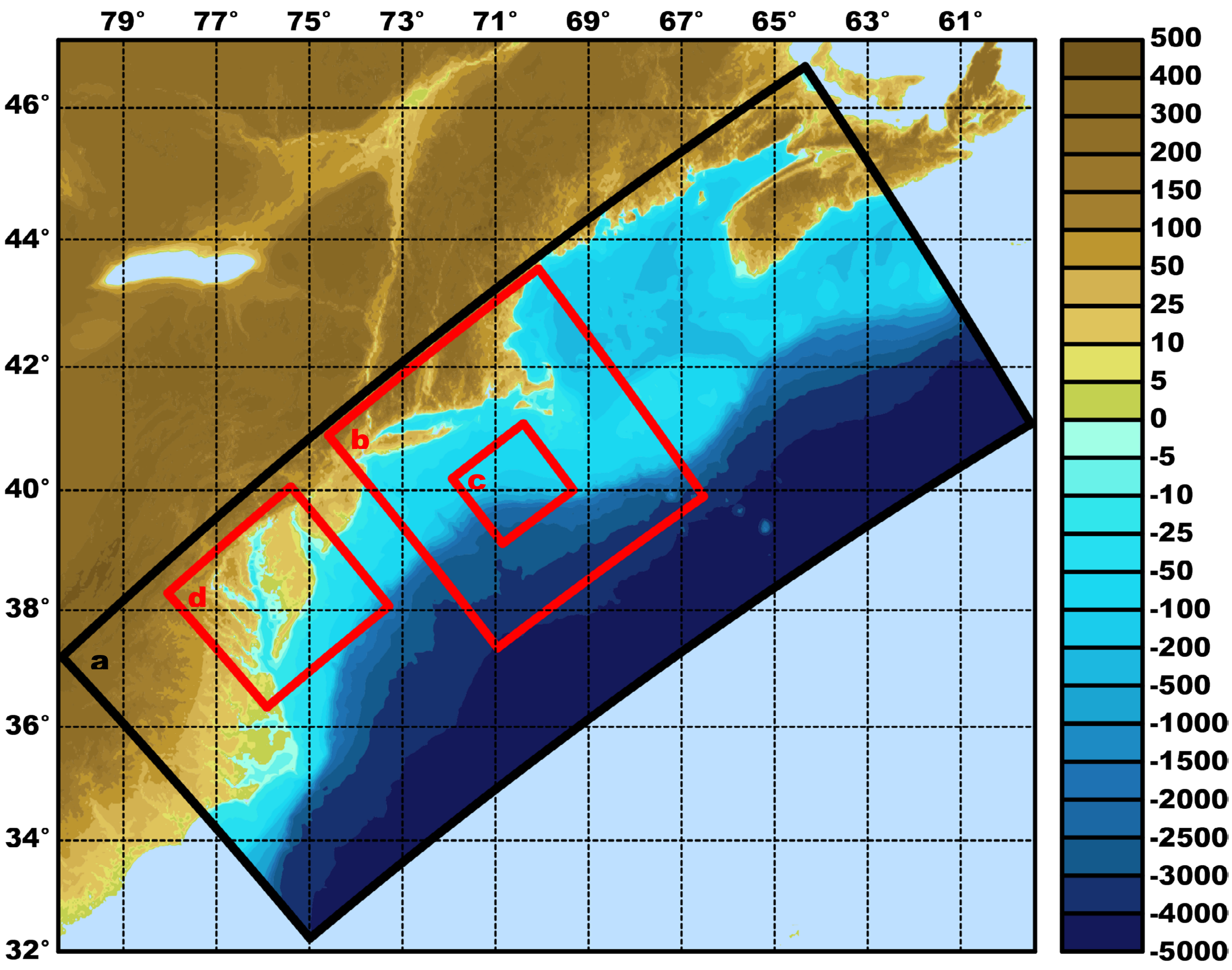

Figure 1: Current ROMS nested grid application for the U.S. East Coast: (a) DOPPIO coarse grid, (b) Hudson Canyon refinement grid (1:3 ratio from a), (c) PIONEER array telescoping refinement grid (1:3 ratio from b), and (d) Chesapeake-Delaware Bay refinement grid (1:5 ratio from a). The average resolutions for the grids are: 7.0km for (a), 2.3km for (b), 1.0km for (c), and 1.8km for (d).

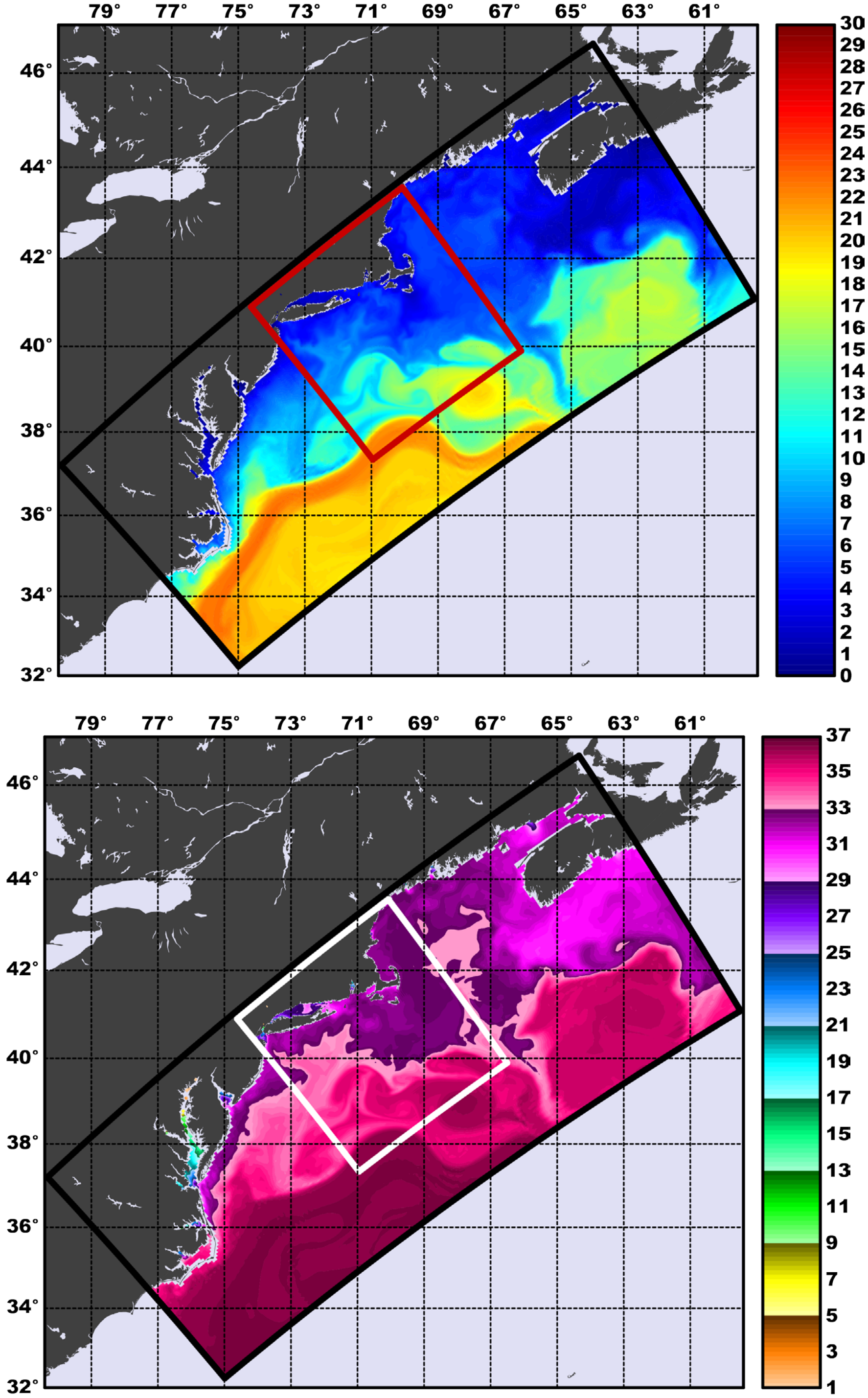

Figure 2: Two-way nested, daily-averaged surface temperature (upper panel; Celsius) and surface salinity (lower panel) for 31-Jan-2014. The refined solution for the Hudson Canyon grid is overlaid on top of the coarser DOPPIO grid. The refinement ratio between coarse and fine grids is 1:3.

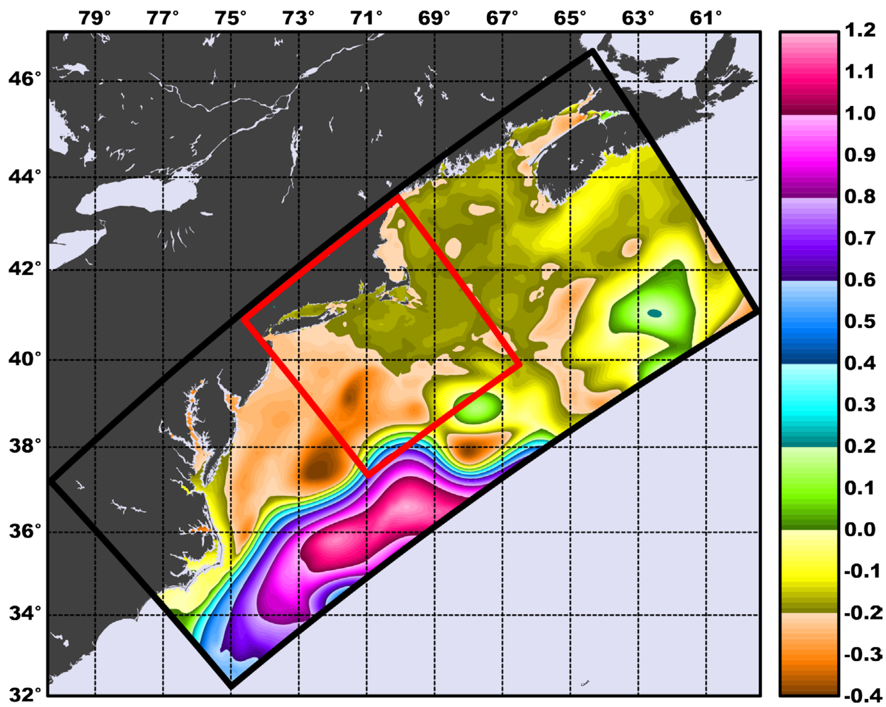

Figure 3: Two-way nested, daily-averaged sea surface height (m) for 31-Jan-2014. The refined solution for the Hudson Canyon grid is overlaid on top of the coarser DOPPIO grid. The refinement ratio between coarse and fine grids is 1:3.

IMPACT/APPLICATIONS

This project will provide the ocean modeling community with a freely accessible, well documented, open-source, terrain-following, ocean model for regional nowcasting and forecasting that includes advanced data assimilation, ensemble prediction, and analysis tools for adaptive sampling and circulation dynamics, stability, and sensitivity.

TRANSITIONS

The full transition of ROMS to the operational community is likely to occur in the future. However, the ROMS algorithms are now available to the developers and scientific and operational communities through the website http://www.myroms.org/.

RELATED PROJECTS

The work reported here is related to other funded NOPP project titled: *Toward the Development of a Coupled COAMPS-ROMS Ensemble Kalman filter and adjoint with a focus on the Indian Ocean and the Intraseasonal Oscillation* by Moore *et al.* (N00014-15-1-2545). The PI (Arango) closely collaborates with A. Moore (adjoint-based algorithms) at University of California, Santa Cruz and J. Wilkin (Mid-Atlantic Bight variational data assimilation) at Rutgers University.

PUBLICATIONS

None.

REFERENCES

Cohn, S., A. D. Silva, J. Guo, M. Sienkiewicz, and D. Lamich, 1998: Assessing the effects of data selection with the DAO physical-space statistical analysis system, *Mon. Wea. Rev.*, **126**, 2913–2926.

Egbert, G., A.F. Bennett, and M. Foreman, 1994: TOPEX/POSEIDON tides estimated using a global inverse method, *J. Geophys. Res.*, **99**, 24,821–24,852.

Gurol, S., A. T. Weaver, A. M. Moore, A. Piacentini, H. G. Arango, and S. Gratton, 2014: B-preconditioned minimization algorithms for variational data assimilation with the dual formulation, *Q. J. R. Meteorol. Soc.*, **140**, 539-556, DOI:10.1002/qj.2150.