Limited Area Coastal Ocean Models: Assimilation of Observations from Fixed Platforms on the Continental Shelf and Far-Field Forcing from Open Ocean Models

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http://sablam.unc.edu/

LONG-TERM GOALS

Coastal oceanographers face the fundamental problem of constructing models that will accurately interpret physical and biological observations, provide reliable forecasts of oceanographic processes, and guide the design of future sampling programs. Recent advances in computing capabilities and marine observation techniques have led to the development of models capable of producing simulations that increasingly approach real-world conditions, establishing at an unprecedented level the opportunity for advancing understanding and management of coastal ecosystems. The goal of this project is to build an operational system for forecasting of the coastal ocean over a limited area, and to demonstrate and test its capabilities.

OBJECTIVES

Our objective is to build an operational system for site-specific, limited-area forecasting of the coastal ocean. The system will be applied and tested in the South Atlantic Bight; it will be modular and portable to other waters. It will feature coupled physical/biological phenomena in and around the South Atlantic Bight Synoptic Offshore Observational Network (SABSOON – http://www.skio.peachnet.edu/research/sabsoon). *In situ* and remotely sensed observations will be assimilated, plus results from atmospheric and global ocean models. Atmospheric products will be handled within the partnership, and the remotely-sensed data will be obtained from standard sources (e.g., SeaWiFS). SABSOON will be the primary source of *in situ* data.

APPROACH AND WORK PLAN

The operational system provides operational nowcasts and forecasts for water level and current for a limited-area region of the South Atlantic Bight. The system is composed of three numerical models and the necessary infrastructure to control the system processes and file management. The system assimilates *in situ* coastal water level and midshelf depth averaged currents into a limited-area coastal ocean model with an inverse/assimilation component. Two separate models ocean models, running asynchronously, comprise the local system.

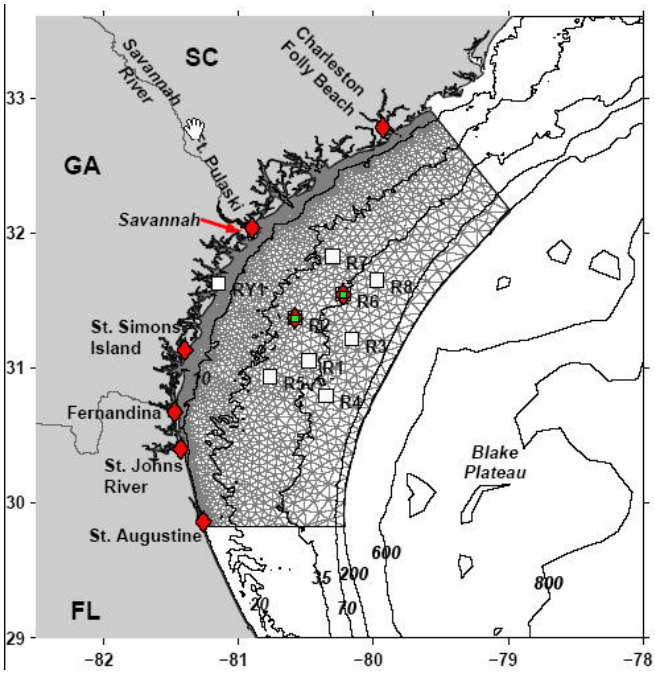

Figure 1. Limited area grid. Red diamonds along the coast are sea level stations used in assimilation. The SABSOON towers are numbered R1-R8.

QUODDY a widely used, limited-area continental shelf model that contains advanced physics, including the 3-D transport of salinity and temperature. It is the central forecast tool; its output includes the surface elevation and water velocity on the limited-area domain (see Figure 1). Its assimilating counterparts (**TRUXTON** and **CASCO**) ingest the misfits between the observed currents

and water levels to provide corrections to the barotropic pressure on the limited-area domain boundaries (this is shown schematically in Figure 2).

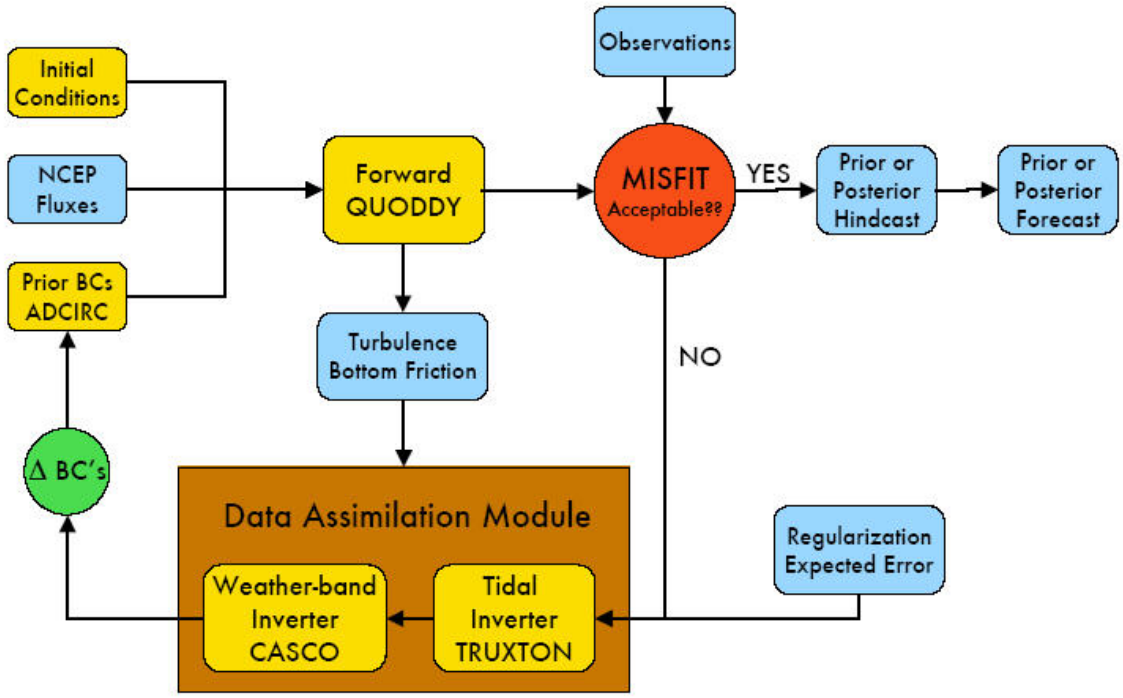

Figure 2. Flowchart indicating the implementation of the operational system including the Truxton/Casco data assimilation module.

ADCIRC is a system of computer programs for solving time dependent, free surface circulation and transport problems in two and three dimensions. The two-dimensional version of ADCIRC is used to provide far-field wind-band and tidal forcing to the limited-area domain on which data assimilation takes place.

Surface momentum flux is gathered from the NCEP ETA operational model product. **ETA** is the primary mesoscale meteorological model of the National Centers for Environmental Prediction that provides gridded analyzed short-term forecast surface wind stress, pressure fields and heat/moisture fluxes to the oceanographic system. Essentially, ETA and ADCIRC provide atmospheric and oceanic forecasts which serve as input forcing for the QUODDY/TRUXTON/CASCO limited-area prediction system. Outputs of all three models are archived for future analysis. Internet access is required among all partners and all forecast products.

The computational environment is a heterogeneous Linux Cluster at the University of North Carolina at Chapel Hill. System procedures (data retrieval/archive, model input preparation, model execution, and post-processing) are centrally controlled by processes that are linked over the Internet.

WORK COMPLETED

Operational modeling: In Mid-April 2003 all components of the system were in place at the North Carolina Super-computing Center (NCSC), a partner in our project. Web-posting of daily hindcasts forecasts was in place. A significant set-back to the project occurred when NCSC shut down on short notice in June 2003 (in part due to decisions by the NC Legislature) and we had to move/reinstall the entire system at UNC-Chapel Hill and the office of Academic Technology and Networks (ATN). The result was the loss of a critical partner (NCSC) and the expertise that it provided. The invaluable skills of the project member at NCSC (E. Sills) have been partially retained. This has been a significant obstacle to overcome as a new system had to be learned. The transfer of files from mass storage from NCSC to UNC took three months, the set up of procedures for acquisition of remotely stored data and atmospheric model output, the set up of automation procedures, etc., has taken over 6 months to re-build. At this point (Feb 2004), we have almost recovered the state of our project of April 2003 and expect to post model results on a daily basis by March 2004. During this operational "down" time, we have extended the hindcast/nowcast system to include assimilation of sea-level available along the Georgia/South Carolina coastline.

Wind convolution: In a continuing series of CASCO inverse model improvements, we have installed a wind-band autoregression element. This feature allows the physics-based reduction of rank and run-time, without compromising skill in the wind-band; it also avoids unphysical inversions which can occur with full-rank approaches. Publication is listed below; the software and user guide are on the Dartmouth web site.

Observational component: Maintenance of the towers by the Navy caused the towers (see Fig 1) to shut down during summer 2003. R2 went back on line 12 Sept. 2003 with both meteorological and in-water packages. The R8-M2 microwave link has been established. The R2 ADCP data quality has degraded, and this is being investigated. There is no communication with the M2R6 ADCP. The M2R6 anchor needs to be replaced. Repeated failures of Young wind monitors have been experienced.

SeaWiFS data assimilation: Inversion procedures have been implemented to fit chlorophyll data in the instances that have been considered. The deduced fields include net chlorophyll production fields.

RESULTS

We completed an extensive tidal analysis of the region. The inclusion of tidal inlets and estuaries in the forward and assimilative modeling was found to be essential in capturing the physics of tidal propagation, and thus sea-level variability, at the semi-diurnal frequencies (Lynch et al. 2003; Blanton 2003). Figure 3 demonstrates the impact of including the estuaries in the forward and inverse model solutions as a fundamental physical/geometric effect. The effect of the estuaries impacts the operational system as shown Figure 4 where a clear tidal signal in the prior solution is significantly reduced by the inversion process that explicitly includes the estuaries. Reduction of sub-tidal misfit is also achieved by the operational assimilation.

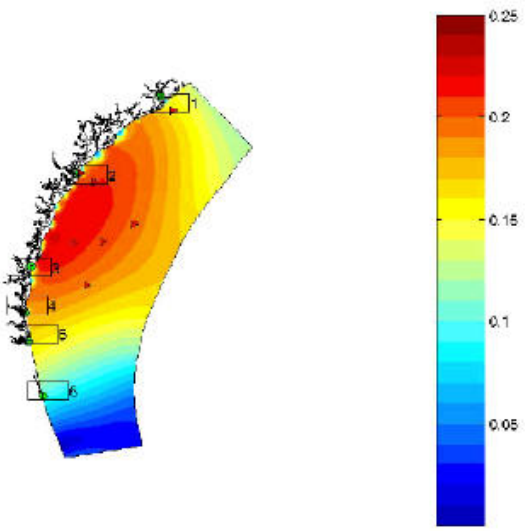

Figure 3. Error (meters) between inverse solutions with and without estuaries (from Lynch et al. 2003). The largest error is located in front of the estuaries along the GA/SC coast.

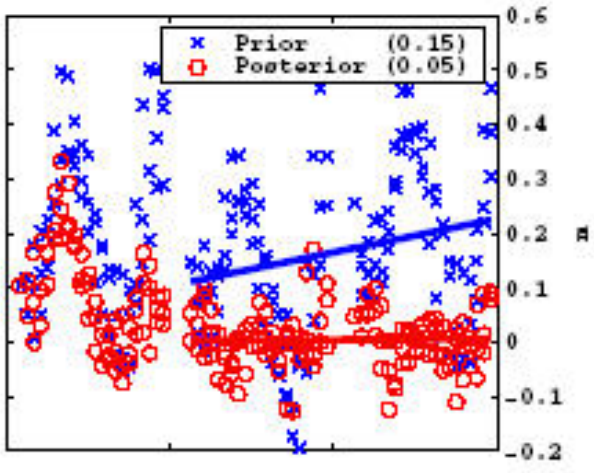

Figure 4. Misfit between observed and computed water levels for the prior (blue) and assimilated (red) solutions over the period October 2-5, 2003 at Fort Pulaski (from Blanton, 2003). The rms error has been reduced from 15 cm to 5 cm.

The inferred biological source/sink terms for a hindcast chlorophyll concentration during November 2002 are realistic and the hindcast flow fields produce a solution with the "best" fit. Extensions to include/correct for cloudiness problems have been successfully explored and a method for compositing cloudy satellite images consistent with the hydrodynamic environment has been established.

National Security

The potential impact of this project concerns the ability to diagnose and forecast phenomena in the coastal ocean, especially the near-shore. All naval and shore-based operations are compromised without this capability.

Economic Development

Commercial operation continues to grow in the US Exclusive Economic Zone, where we are making forecasts. Marine transportation, all marine resource exploitation (oil and gas, fisheries), and waste disposal increase pressure on the quality of marine forecasts.

Quality of Life

As mentioned above: public and ecosystem health as well as coastal resource management are the joint responsibility of citizens, corporations, and government agencies. In particular, accurate forecasts of the coastal ocean are critical to forecasting the occurrence of "red tide" or harmful algal bloom events which directly impacts public health.

Science Education and Communication

The PI's are involved daily with university education in both private and public sectors. This research has direct curricular relevance in ocean and environmental science.

TRANSITIONS

Generally, we are seeking to transition this system to an operational agency.

RELATED PROJECTS

HYCOM Consortium (http://hycom.rsmas.miami.edu/). Funded by NOPP, HYCOM is part of the US Global Ocean Data Assimilation Experiment (GODAE). We are collaborating with the HYCOM consortium to explore the use of HYCOM as a provider of boundary and initial conditions to limited area coastal models. This includes the effects of the model Gulf Stream on our shelf region (Figure 5).

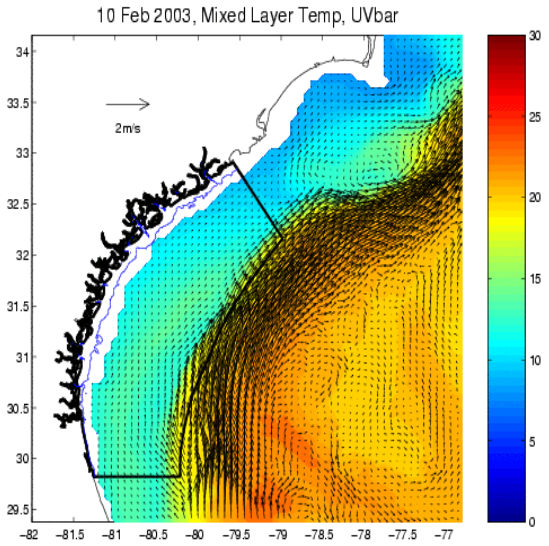

Figure 5. Overlay of our limited area model (outline) with HYCOM/GODAE domain (depth averaged and surface temperature). We are addressing differences in model coastal boundaries and bathymetry.

SEA-COOS (http://www.seacoos.org). The SouthEast Atlantic Coastal Ocean Observing System is an information system that collects, manages and disseminates observations and information products in the coastal ocean off North Carolina, South Carolina, Georgia and Florida. Due to the regional overlap, institutions and investigators involved in the two projects, approaches in data collection and modeling are shared between this project and SEA-COOS.

ECOHAB-GoM: (http://www-nml.dartmouth.edu/circmods/ecohab/). This NOAA-COP project is focused on forecasting Harmful Algal Blooms in the Gulf of Maine. Assumed is a hindcast/ forecast capability for the Gulf of Maine Coastal Ocean, and a biological simulator operating in tandem. PI's include Lynch and McGillicuddy.

PUBLICATIONS

Blanton, B.O. (2003) Towards operational modeling in the South Atlantic Bight. Univ. of North Carolina at Chapel Hill. http://www.unc.edu/~bblanton/dissert/dissert.html

Blanton, B. O., A. Aretxabaleta, F. E. Werner, and H. E. Seim (2003) Monthly climatology of the continental shelf waters of the South Atlantic Bight, *J. Geophys. Res.*, *108*(C8), 3264, doi:10.1029/2002JC001609, 2003.

Lynch, D.R. and K. Smith (2004) Wind-Based Convolution in Limited-Area Coastal Ocean Forecasting: inference and persistence. *Proc. Computational Methods in Water Resources*, U. North Carolina-Chapel Hill, June 2004.

Lynch, D., K. Smith, B. Blanton, R. Luettich, F. Werner Forecasting the Coastal Ocean: Resolution, Tide, and Operational Data in the South Atlantic Bight. *J. Atmos. Oceanic Tech*. Accepted November, 2003 (in press).

Hannah, C.G, D.R. Lynch, K.W. Smith. CASCO 4b Users' Guide. Can. Tech. Rep. Hydrog. Ocean Sci. 226: vii +80 pp. Government of Canada, 2003.

Reports available from: http://www-nml.dartmouth.edu/Publications/external_publications/:

NML-03-15: BATTRI: 2-D Finite Element Grid Generator
Keston Smith and Ata Bilgili
November 11, 2003
NOTE: see NML-01-2 for previous versions.

NML-03-14: PELOSAB: Finite element mesh generation Tutorial: Using BATTRI
Alfredo Lopez de Aretxabaleta
December 15, 2003

NML-03-11: A comparison of the ensemble Kalman Filter and ensemble smoother as sea surface temperature forecast algorithms in the South Atlantic Bight
K. Smith
Poster Presentation, Gordon Research Conference on Coastal Ocean Modeling, June 2003

NML-03-10: Resolve the Tide or Lose the Data
K. Smith, D. Lynch, B. Blanton, C. Werner, R. Luettich
Poster Presentation, Gordon Research Conference on Coastal Ocean Modeling, June 2003

NML-03-9: OACI Users' Manual (Objective Analysis for Circulation Initialization)
K. Smith , October 2003

NML-03-8: CASCO 4C Addendum, Time Series Convolution
K. Smith and D. Lynch, October 2003

NML-03-6: Implementation of the South Atlantic Bight Limited Area Model
B. Blanton, R. Luettich, E. Sills, A. Aretxabaleta, H. Seim, F. Werner, D. Lynch, K. Smith, D. McGillicuddy, J. Nelson, Gordon Research Conference Poster, June 2003

NML-02-7: A Simple Guide (with Examples) to Generating a Finite Element Mesh of Linear Triangular Elements Using Battri, Karen Edwards and Francisco Werner, 14 July 2002

PRESENTATIONS AT PROFESSIONAL MEETINGS

Downes, J.H., J. D. Lambert, and P. Welsh 28th Annual of the National Weather Association, 18-23 October 2003, Jacksonville, FL. Comparing Wireless Network Protocols for Environmental Sensor Networks (ESNs)

Welsh, P.T. NOAA Tech 2004 Wireless Environmental Sensor Networks (available online) http://www.tvworldwide.com/events/noaa/031021/agenda_031023.cfm

Welsh, P., B. Shaw, A. Wildman, J. Smart, B. Meisner, and J. Savadel NOAA's Coastal Storms Initiative (CSI) in Northeast Florida and the NWS Local Mesoscale Modeling Project

Welsh P., A. Wildman, B. Shaw, J. Smart, P. Ruscher, J. Savadel and J. McGinley 84th Annual AMS Conference, 16th Conference on Numerical Weather Prediction, 11-16 January 2004, Seattle WA. Implementing the Weather Research and Forecast (WRF) model with local data assimilation in a National Weather Service Weather Forecast Office (WFO)

Nelson, J. and H. Seim. AGU Fall Meeting, Dec. 2002. Initial Results From SABSOON: A Coastal Ocean Observatory on the South Atlantic Bight Continental Shelf.

2003 Gordon Research Conference poster presentations. Please refer above to the reports listed as # NML-03-11 (Smith), # NML-03-10 (Smith et al), and # NML-03-6 (Blanton et al).