A US IOOS COASTAL AND OCEAN MODELING TESTBED TO IMPROVE PREDICTION OF COASTAL AND ESTUARINE SYSTEMS

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Abstract

The U.S. IOOS Coastal and Ocean Modeling Testbed (COMT) has recently completed its first highly productive phase and has facilitated strong and strategic collaborations among experts from academia, federal operational centers and industry. The purpose of the COMT has been to accelerate the transition of scientific and technical advances from the coastal ocean modeling research community to operational ocean products and services. To do this, the COMT supports targeted efforts to increase the accuracy, reliability, and scope of predictive coastal ocean models that are currently being run or are under consideration for operational use by one or more federal agency. Capabilities that have been realized or that should evolve from a COMT include:

- Quantitative data on the behavior and implementation requirements of multiple models that are presently in operational use or that are under serious consideration for such use.
- Timely improvements to models for operational use.
- An organized archive of observational data, model inputs and model results that can be used for model testing and evaluation both during and after specific Testbed activities.
- Tools that leverage or, as necessary, define community standards to enable the efficient access, visualization, skill assessment and other evaluations of multiple model results.
- A cyber-supported research environment where researchers and operational agencies can work together to transition models from research to operations.
- Creation of a community engaging governance structure used to set research priorities and standards for data interchange.

Key words: modeling, prediction, forecasts, testbed, cyberinfrastructure, operations

1. INTRODUCTION AND BACKGROUND

Coastal ocean and estuarine environments along with adjacent shorelines, wetlands and lowlands are threatened by climate change, sea-level rise, storm-induced flooding, anthropogenic nutrient and contaminant inputs, oxygen depleted “dead zones”, oil spills, harmful algal blooms and other unforeseen factors. Effective management of these environments requires the operational use of predictive models. We define operational use to cover a wide range of society-critical applications including: forecasts (e.g., 4x365 or event based forecasts), hindcasts (e.g., event based forensic studies), risk assessment (e.g., 100 yr flood levels), design (e.g., flood protection systems) and management (e.g., nutrient management).

NOAA is working on research and development projects to improve forecasts of coastal processes having a strong socioeconomic relevance. For example, improved coastal inundation and storm surge forecasting is being pursued through a holistic, community approach described in NOAA’s Storm Surge Roadmap (http://www.stormsurge.noaa.gov/r_and_d.html). Similarly, the NOAA Ecological Forecasting Roadmap (http://oceanservice.noaa.gov/topics/coasts/ecoforecasting/ecoforecasting.pdf) has established priorities and should help to facilitate community collaborations to improve the quality and delivery of ecological products such as predictions of harmful algal blooms, sea nettles,
pathogens and hypoxia. These forecasts can help coastal managers and scientists make better decisions in areas ranging from emergency response, to nutrient management to public health.

During the past two years, the Southeastern Universities Research Association (SURA) has led a highly productive initial phase of the U.S. IOOS Coastal Ocean Modeling Testbed (COMT). During this time a flexible and extensible community research framework (including a supporting “cyber-infrastructure” and an interdisciplinary network of scientists and users) has been developed to advance the testing and evaluation of predictive models of key coastal ocean environmental issues. This framework supports integration, comparison, scientific analyses and archiving of data and model output. The cyber-infrastructure that has been developed includes a repository of data assembled from numerous observations and models as well as tools for comparing and assessing the models and data.

Three research challenges of high socioeconomic relevance: estuarine hypoxia, shelf hypoxia, and coastal inundation, have been pursued in the initial COMT. Advancements in predictive modeling capabilities resulting from the Testbed include:

- A multi-model ensemble was found to yield more accurate predictions of the “dead zone” in the Chesapeake Bay than any one of the models evaluated in this component of the testbed. Ensemble modeling has been recommended to the Chesapeake Bay Program for forecasting future water quality conditions in the Bay (Figure 1).

- Improvements were achieved in the skill of models for predicting the timing and location of hypoxic “dead zone” conditions in the Chesapeake Bay. Dead zones have a significant impact on living marine resources; predicting their occurrence is critical for ecosystem management within the Bay.

- A simple dissolved oxygen formulation for forecasting the location and timing of seasonal hypoxia was transitioned to NOAA/CSDL’s research version of the Chesapeake Bay Operational Forecast System (CBOFS) for evaluation (Figure 1).

- A synoptic scale modeling capability was demonstrated for predicting the timing, duration, spatial extent, and severity of the northern Gulf of Mexico ‘dead zone’. This capability has helped reduce uncertainties about the role of nutrient loads in generating the ‘dead zone’. Model transition to NOAA/CSDL is underway for further evaluation.

- The evaluation of three unstructured grid, coupled wave and surge models demonstrated the efficacy of these models for high resolution predictions of storm surge coastal flooding by nor’easters in the Gulf of Maine. This work demonstrated the efficiency of nesting local area models within a coarse, regional model in areas of relatively steep coastal topography and the importance of wave effects on coastal flooding.

- Storm surge and coastal flooding due to hurricanes in the northwestern Gulf of Mexico were shown to be the result of a forerunner (due to Ekman setup in advance of the storm) as well as direct onshore winds near the time of storm landfall. An evaluation of three unstructured grid, coupled wave and surge models and the NWS SLOSH model demonstrated the sensitivity of model domain size and the parameterizations of surface stress and bottom friction to accurately predicting both the forerunner and the land-falling response (Figure 2).

Figure 1. Simple models reproduce dissolved oxygen and hypoxic volume as well as more complex models; a five-model average does better than any one model alone.

Figure 2. Water level time series for 4 models as compared to observations for Hurricane Ike.

A version of SLOSH that is coupled to a wave model was developed in the Testbed and is now being tested by the National Hurricane Center. One
of the unstructured grid models will be evaluated during the coming year as part of the NOAA Hurricane Forecast Improvement Program.

- The model archive and tools developed by the cyber-infrastructure component of the Testbed are being used both by Testbed participants and by operational groups that were not part of the initial Testbed to improve model evaluation, skill assessment and visualization (Figure 3).

A less tangible product of the initial Testbed, but one that will have a significant lasting impact, is the community-building that resulted from scientists working together on the shared goal of improving model performance. In several cases when one model was found to have less skill than others, the Testbed modelers worked together to figure out the cause of these differences, and to improve the underperforming model. These interactions and feedbacks resulted in significant improvements to several of the models evaluated in the Testbed. For example, the Estuarine Hypoxia team reported that the ChesROMS model realized a 40% overall reduction in RMS difference between predicted and observed bottom dissolved oxygen concentration due to improvements identified during the Testbed.

Despite needing to predict significantly different quantities, there are a number of common requirements of the various users, such as:

- guidance for the appropriate / optimal use of individual models and model ensembles;
- systematic model skill assessment and the development of quantitative model error metrics;
- measures of model performance on available computer architectures;
- means for determining the value of new models versus existing models particularly when a change in models requires significant investment in training, computing infrastructure, scheduling, etc;
- means for choosing between multiple competing models;
- tools to efficiently visualize and analyze model output, particularly from multiple models; and
- tools to allow Matlab and Python users to consume model data for analysis, including unstructured grid models.

3. STATE OF THE OBSERVING SYSTEM AND TECHNOLOGY

The general states of observing system and modeling technologies for coastal and estuarine environments are evolving at a rapid pace. Observing systems remain challenging to operate and maintain in the marine environment, although the continued improvement of sensor, platform (e.g., AUVs) and communications technologies are providing unprecedented amounts of observational data from the near shore environments. Predictive models are available for hydrologic runoff; water quality and ecosystems response including nutrients, contaminants, dissolved oxygen, lower and upper trophic levels; oil spill transport; storm surge and flooding; waves; tides; sediment erosion and transport; and numerous other coastal and estuarine phenomena.

Missing from this picture is an efficient means of taking advantage of new data streams and modeling advancements to improve the predictive modeling capabilities of operational users. To meet this large gap, we recommend the creation of a permanent Coastal and Ocean Modeling Testbed within the US IOOS program.

4. INTEGRATION WITHIN IOOS, MODELING, AND DMAC

The recommended US IOOS Coastal and Ocean Modeling Testbed (COMT) would be targeted to high priority modeling applications as identified by operational users and the IOOS community. Thus it
would complement existing IOOS modeling activities by providing a well-configured and well-maintained environment for model evaluation. Testbed activities would change on a multi-year basis and the data generated therein (e.g., model grids, forcing, output and companion observational data) would be available for future use by the modeling community. For example, IOOS has identified two high level priorities for the COMT:

1. Maintain and continue to develop the COMT within a community modeling environment in particular with respect to the cyberinfrastructure to enable data infrastructure, standards and metrics for conducting both model development and model skill assessment. The Testbed would utilize existing IOOS DMAC standards to the extent they are adequate and help define new standards as needed by the IOOS modeling community.

2. Address key scientific and technical challenges facing NOAA. Specifically, assess the maturity, readiness and user applications of coastal ecological models of Harmful Algal Blooms, Hypoxia and Pathogen predictions. For inundation forecast models, NOAA is interested in identifying potential operational models with ability to represent inundation due to precipitation and storm surge in areas of steep topography. It is also a high priority for NOAA to assess coastal data assimilation approaches and methodologies so as to determine and assess the suitability of existing observing networks for operational modeling and coastal prediction.

5. THE WAY FORWARD FOR THE NEXT TEN YEARS

The long-range vision of the COMT is to increase the accuracy, reliability, and scope of the federal suite of operational ocean modeling products to meet the needs of a diverse user community.

The mission of the US IOOS COMT is targeted research and development to accelerate the transition of scientific and technical advances from the coastal ocean modeling research community to improved operational ocean products and services. Activities conducted in the COMT should help determine how to implement models more effectively, how to improve knowledge of model uncertainty, how to better integrate observations and models, and how to transition recent advances in algorithms, parameterizations, evaluation tools, and more, into models that are used operationally. Specific capabilities that we expect a Testbed to provide are outlined below.

5.1. Community Governance

An inclusive governance structure must be in place that provides adequate oversight and operational user inclusion. This will ensure appropriate setting of research priorities and participation in evolving structures, such as the NSF EarthCube and DataWay, both programs for supporting the development of community-guided cyberinfrastructure to integrate data and information for knowledge management across the sciences.

5.2. Model Implementation Requirements

A key function of a robust COMT is to collect and evaluate quantitative data on the behavior and implementation requirements of models that are presently in operational use or that are under serious consideration for such use. A goal is to develop a system to evaluate the feasibility, costs and benefits of improving existing operational capabilities and transitioning new models into operational facilities. Testbed outcomes should include guidance on implementation issues such as model grid resolution and parameter values and on observational data needs for assimilation and skill assessment.

5.3. Archive of Observational Data, Model Input for Model Evaluation

The COMT will support an organized archive of observational data, model inputs and model results, compliant with IOOS DMAC standards, which can be used for testing and evaluating both current and future models. The archive will be accessible to modelers as well as non-modelers, to stakeholders and decision-makers (Figure 4).

5.4. Modeling Evaluation Tools

Tools that leverage or, as necessary, define community standards to enable the efficient access, visualization, skill assessment and other evaluations of multiple model results are expected products of the COMT.

5.5. Cyber-infrastructure Tailored to Modeling Needs

The COMT will provide a research environment, or cyber-infrastructure, where researchers and operational agencies can work together on selected modeling applications as a means of fostering and enhancing the transition of models from research to operations.

6. CONCLUSIONS

The Coastal Ocean and Modeling Testbed (COMT), briefly introduced in this paper, has made significant advances in assessing the skill of a variety of numerical models and has supported development and
testing of protocols and tools for assessing and comparing models and enabling open access to observational data and modeling results. In the coming years, further advances will be required to bring the COMT to full maturity. By facilitating the advancement of science-based models coordinated with supporting observations, the COMT can enhance the nation’s ability to predict and manage coastal risks arising from unforeseen events as well as from environmental and societal change. These capabilities should be readily extensible to other geographic regions and to other environmental focus areas.

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Figure 4. Prototype model explorer web site to allow users to access model and observation data