COMMUNITY MODELS AND INTEGRATED OBSERVATIONS FOR THE CHESAPEAKE BAY

An Initiative of the Chesapeake Research Consortium

PREAMBLE

As North America's largest and best-known estuary, the Chesapeake Bay is a national resource deserving of a sustained commitment to protect and restore its living resources that is based on a sophisticated scientific understanding of its ecosystem. When considered in its entirety, the Chesapeake Bay is intimately coupled with the continental shelf regime of the Middle Atlantic Bight and with the watershed systems that supply the Bay with freshwater, sediments and nutrients via numerous river estuaries, notably the Susquehanna, Patuxent, Potomac, Rappahannock, York, and James. The Chesapeake Bay serves as the Atlantic gateway to two of the East Coast's major deepwater ports, Hampton Roads, Virginia and Baltimore, Maryland, and future developments are expected to involve deepening the access to Chesapeake Bay by five feet (1.5 m), which could have dramatic effects on the Bay ecosystem.

The future of marine-related industries will sustaining natural resources and environmental quality while at the same time facilitating the most effective possible development plans. This will require significantly improved physical and ecological models that can be employed in decision-making. Decision-makers must deal not only with projected anthropogenic changes but also with the natural regime of the Chesapeake Bay, which is energetic, temporally variable and may be undergoing, or about to undergo, subtle but highly significant changes in response to changes in climate.

For these and other reasons, there is urgent need for long-term program of integrated scientific observations and ecological modeling that takes into account estuarine circulation, nutrient dynamics, plankton ecology, benthic ecology, living resources, and sediment dynamics, among other factors. Numerically based models are essential tools for deciphering key ecosystem processes, understanding how the various biological, chemical, and physical processes are integrated into the complex whole, developing predictions about environmental change, and translating results into practical applications that will aid in the management of coastal resources. Ongoing scientific observations of Bay organisms and the environmental factors that affect them are requisite for iterative testing of the accuracy of the models.

Given the strong observational and modeling capabilities of the Chesapeake Research Consortium (CRC), the significant accomplishments of the Chesapeake Bay Program, and the compelling need to provide a firmer basis for water quality management, the Chesapeake Bay is the ideal focus for a new, cooperative initiative. The goal of this initiative is *to provide the scientific foundation for the next generation of coupled estuarine circulation/ecology models that are based on sound ecological "ground-truthing"* And sustained time series of key parameters. The CRC is an ideal mechanism for coordinating and providing focus for this multi-state, multi-institutional effort. Hence, we, the principals of the CRC, commit to ensuring that observational data and model developments are shared freely among the CRC community of scientists.

THE NEED FOR NEW APPROACHES TO MODELING

The Chesapeake Bay Water Quality Model is currently relied upon to guide management decisions and project the potential outcomes of nutrient reduction strategies for the Chesapeake Bay Program. Although it is likely that managers will continue to rely on this model until a suitable replacement is developed, numerous members of the scientific and management community recognize that this model is becoming outdated and suffers from inadequate integration of observational data, among other flaws. However, new modeling approaches, including those that use data assimilative techniques, are now used effectively in other arenas. Data assimilation involves inclusion of data to drive boundary conditions and allows components of the model to be replaced with observed data. Provided that the modeling efforts are closely coordinated with high-quality integrated observational (or "monitoring") strategies, such approaches should significantly improve model reliability. Further, modeling should take more explicit account of event-driven (e.g. hurricanes or severe floods) processes and of the fact that the Bay is tightly coupled with the inner continental shelf of the Middle Atlantic Bight. They should take advantage of cutting-edge developments in the component models (hydrodynamic, sediment transport, coastal interaction, bio-optics/primary production, and plankton/ benthic/higher trophic level ecology).

The time has come for a new approach to environmental modeling to emerge and flourish. This approach will involve the creation of new generations of dynamic models that are well documented, that permit model uncertainty to be quantified, that are verified and refined by means of integrated high-quality observations, and that enter the public domain for scrutiny and refinement soon after their initial validation. Most significantly, it is envisioned that the creation and sharing of component model "building blocks" will enable different applications and scientific objectives to be more effectively addressed by making it possible for any user to assemble the appropriate composite model. Accomplishment of the advances that we advocate will require that the academic scientific community be more directly engaged in the processes of model development and data integration. At the front end of the modeling program, the academic community is best able to pose the fundamental scientific questions (though not necessarily the most compelling management questions) that the models and observations must address. We believe that CRC can play a key role in facilitating and coordinating the engagement of academic scientists. We therefore commit to supporting, within our individual institutions, new and creative approaches to modeling and/or the provision of integrated observational data to the modeling effort. To the extent feasible, we will seek new resources, or where appropriate redirect existing resources to this end.

SHARED MODELS

A key feature of this CRC initiative will be to identify, develop and continually evolve community-shared models. Choosing community-shared models will allow us to focus our model development resources more efficiently, and will simplify the development of coupled system models. Some guiding principles for these models include the following:

- ***Models should be open source and supported by a substantial user community***

  Open source is necessary to allow many users to participate in development and is a virtual requirement for publication. A substantial user community is necessary to ensure basic model development (boundary conditions, mixing parameterizations, bugs, etc.) as well as an understanding of model quirks. It is reasonable to assume, however, that the user community will possess the expertise required to understand the general limitations and range of applications of the models selected for fusion with other models in order to avoid inappropriate hybridization.

- ***Models should have institutional homes.***

  Experience from successful community modeling efforts has shown that each model or suite of models should be supported by an institutional caretaking activity, providing expertise, archiving, distribution, education, and coordination. Consistent with this agreement, it is accepted as a responsibility of each home institution to provide reasonable support in enabling the implementation of that institution's models by other institutions. Thus, we envision the sharing not only of models but also of training in the effective use of the models.

- ***Data integration, prediction and uncertainty quantification are essential aspects of the modeling process.***

  An integrated observational and data management effort will be crucial to support the construction and testing of models, to support data assimilation for improving predictive capabilities. Uncertainty quantification and management is also of primary importance, especially for model applications.

- ***Modeling activity should be integrated into the educational mission of the CRC institutions.***

  The primary goal of the proposed modeling initiative is to improve our understanding of estuarine ecosystems. Thus the next generation models will be capable of addressing more than a single system, and more than management needs. Students must be trained to deal with a variety of modern, complex models, including open-code models, data assimilating models and coupled models of circulation, ecology and living resources.

- ***Models should incorporate modern numerics as well as improved physical/biological parameterizations.***

  Modern numerics and physics have self-evident advantages. It also is a requirement for development continuing into the future, including implementation on modern computer architectures.

Implicit in the concept of shared models is the idea of synergistic model evolution. That is, by readily accessing each other's models, scientists are expected to gain new insights with respect to their own research and model development and make those insights known to their colleagues. It will be through such collegial exchanges that models evolve. We therefore commit to nurturing an environment that encourages, facilitates and rewards the sharing not only of models, but also of insights, criticisms and ideas for new model refinements. This commitment shall not contravene any intellectual property or proprietary agreements that may exist between institutional investigators and funding agencies or industry.

INTEGRATED OBSERVATIONS

Most existing models are confounded, to varying degrees, by the complexity and non-linearity of coastal systems. Anthropogenic modifications and impacts exacerbate this situation. Consequently, many simplifying assumptions that are justified in the case of the deep sea are rendered invalid in coastal waters. Put simply, there are mechanisms and phenomena operating in estuaries and shallow coastal waters that are not yet accounted for in models. Observational data are increasingly needed to verify and refine predictive models. When used interactively with models, for example through assimilative methodologies, such data can also facilitate short-term "nowcasting" whereby predictions of impending phenomena are frequently refreshed to apply to the most recent observations. In addition to better anticipating the long-term trends sought by the Chesapeake Bay Program, this process can considerably enhance the reliability of short-term predictions of such things as storm hazards, oil spill trajectories and harmful algal blooms. Perhaps more importantly, observational data are essential to document poorly understood processes not predicted by the models.

It is by way of iterative interactions between models and observations that new and improved generations of models evolve. This fact has long been recognized and has, for several decades, motivated coastal monitoring and remote sensing programs. Unfortunately, until recently, most of these efforts have been seriously handicapped by technological limitations and a lack of sustained funding. Although more or less continuous time series of physical parameters, such as tidal elevation and wave statistics have long been accessible for selected locations, water quality and biological monitoring have relied on monthly or weekly sampling excursions by boat. These excursions have thus offered snapshots in time rather than true time series from which different frequencies (e.g. diurnal to event-scale) of variation could be resolved. Most seriously, boat-supported observations are precluded during extreme storm events when fundamental changes may be occurring. What are urgently needed and are now technologically realizable, are robust multi-parameter observing systems for coastal waters that can provide reliable high frequency time series of essential parameters during all conditions and make the data accessible in near real time.

To date, the instrumented buoy systems of the Chesapeake Bay Observing System have provided data largely on the upper, or Maryland, portion of the Bay although some limited physical parameters, such as tides, currents and winds are also available for the lower Bay. A comprehensive observing system for the lower Chesapeake Bay and its contiguous estuaries and Middle Atlantic Bight shelf waters is long overdue for implementation. Plans to expand observations into this region are well underway and funding has been secured from the Virginia General Assembly for partial support of the effort. Observations from various parts of the watershed are also needed. Over time, and through the combined efforts of all of the CRC institutions, we should be able to assemble a comprehensive observing system for the entire Chesapeake Bay and its watershed. In the context of a new modeling initiative, the purposes of such a system should be to:

- *Obtain long time series of the fluxes of energy, nutrients, sediments, contaminants to, and organisms within, Chesapeake Bay from fluvial and oceanic sources;*
- *Document the effects of these fluxes on coastal marine and estuarine ecosystems;*
- *Utilize the results to improve models capable of predicting environmental changes on multiple time scales; and*
- *Make the quality-assured data and model results available to the marine science community and non-scientist users in near real time.*

Recognizing the need to obtain integrated and sustained time series of multiple physical, chemical and biological parameters from multiple sites in order to verify and refine models as well as to gain deeper understandings of the phenomena we wish to model, we commit to work together toward the goal of creating and expanding an observational network that embraces the entire Chesapeake Bay and its watershed. As we succeed in adding new long-term observing sites to the evolving network, we agree to make the data from our respective institutes' sites available to the entire community in real time or as soon as the essential QA/QC data screening can be completed.

THE ROLE OF THE CHESAPEAKE RESEARCH CONSORTIUM

CRC will assist in integrating modeling and modeling activities to include data assimilation, optimal interpolation of results and adaptive sampling schemes. CRC will facilitate collaboration and to strengthen the individual institution's modeling efforts. CRC can also promote inter-institutional collaboration and cooperation with the larger scientific community by organizing and supporting workshops, conferences and web sites. CRC will also provide community-level support for modeling and monitoring activities, and serve as a clearing house for code and documentation on models of various scales. In addition, CRC will assist in developing protocols for model verification, calibration and documentation.

By this agreement, we commit the institutions of the Chesapeake Research Consortium to promote the protection, restoration and understanding of the Chesapeake Bay and its coupled watershed and shelf waters through a new initiative seeking better models and integrated physical, chemical, biological and ecological observations. We embrace the concept that this initiative can be best accomplished through unselfish and timely sharing of evolving models and observational data. We agree to seek and assign the resources necessary to improve models and make them accessible and to implement the observing systems. We further agree to nurture working environments that encourage, facilitate and reward faculty engagement in the processes of model refinement, data fusion and collegial sharing of new developments and insights.

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For The Johns Hopkins University

For Smithsonian Environmental Research Center

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