Modeling Needs Related to the Regional Observing System in the Gulf of Maine

Gulf of Maine Ocean Observing System
Coastal Observing Center of the University of New Hampshire

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Bigelow Laboratory for Ocean Sciences
Dartmouth College
Department of Fisheries and Oceans Canada
Huntsman Marine Science Centre
Maine Department of Marine Resources
U.S. Environmental Protection Agency
U.S. Geological Survey
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Regional Association for Research on the Gulf of Maine

The Regional Association for Research on the Gulf of Maine (RARGOM) was founded in 1991, as an association of research institutions. Its mission is to foster quality scientific research on the Gulf of Maine through increased communication and collaboration among the region's institutions. The Association stimulates, facilitates, and advocates scientific research focused on the Gulf of Maine as a natural system. The Association provides an independent and neutral forum for discussions; it also coordinates and helps to support meetings and workshops on issues of broad community interest, most effectively undertaken by a consortium. Member institutions are located in both the United States and Canada. RARGOM is currently headquartered at the University of New Hampshire, Durham, New Hampshire.

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For additional publications in this series, see:
Gulf of Maine Data and Information Systems: Workshop Proceedings, RARGOM Report 93-1
Gulf of Maine Circulation Modeling: Workshop Proceedings, RARGOM Report 94-1
Gulf of Maine Habitat: Workshop Proceedings, RARGOM Report 94-2
The Health of the Gulf of Maine Ecosystem: Cumulative Impacts of Multiple Stressors, RARGOM Report 96-1
Gulf of Maine Ecosystem Dynamics, RARGOM Report 97-1
Mechanisms for Improving the Integration of Science and Management in Decisions Affecting the Environmental Quality of the Gulf of Maine, RARGOM Report 97-2
Gulf of Maine Ocean Observing System, RARGOM Report 98-1

Establishing a Framework for Effective Monitoring of the Gulf of Maine, RARGOM Report 00-1

Scientific Workshop on the Gulf of Maine Ocean Observing System, Inc. (GoMOOS, Inc.) RARGOM Report 02-1

Table of Contents

Foreword .... p. 5

Executive Summary
Jeffrey Runge .... p. 7

Plenary Papers
The Relevance of Modeling to Coastal Management in the Context of an Ocean Observing System for the Gulf of Maine
Josie Quintrell .... p.

Gulf of Maine Circulation Modeling: Prospects for Skill and Critical Issues
Daniel Lynch .... p.

Incorporating Fisheries Oceanography into Ecosystem Based Management for Fisheries
Ken Drinkwater .... p.

Coastal Management Issues from a Water Quality Perspective,
Robert Chen .... p.

Ocean Observing and Operational Oceanography in Canadian Waters
David Brickman .... p.

Coupling Basin Scale to Gulf of Maine Models
Robert Beardsley .... p.

Present Status of Observing System Sample Collection and Data Acquisition
David Mountain .... p.

Coupled Physical Biological Models and the Observing System: the Rhomboid Approach
Peter Wiebe .... p.
Dougie Spiers .... p.
Marina Chifflet and Frederic Maps .... p.

Working Group Reports
The Management-Research Connection in Relation to the Observing System........ p.

Data Needs and Critical Issues for Models in the Context of Observing System........ p.

Visions and Roles for a Regional Modeling Center .... p.

Recommendations and Research Priorities........ p.

References

Appendix A: Summary Recommendations from Previous Meetings........ p.

Appendix B: Workshop Agenda.. p.
Appendix C: Participants.. p.
Appendix D: Poster Abstracts .... p.
Appendix E: Red Tide Session.. p.

Foreword

A number of federal agencies and regional and state organizations contribute to the acquisition of time series data on physical, chemical and biological variables pertaining to the Gulf of Maine and its ecosystems. The list includes, but is not limited to, the Gulf of Maine Ocean Observing System (GoMOOS), the Northeast Fisheries Science Center (NMFS sampling programs), Fisheries and Oceans Canada (The Atlantic Zonal Monitoring Program), the University of New Hampshire (Coastal Observing Center), the Woods Hole Oceanographic Institution (Martha's Vineyard Coastal Observatory), the National Estuarine Research Reserves, the Environmental Protection Agency, the Gulf of Maine Council (Gulfwatch) and various other federal, state and provincial fisheries and coastal management agencies and organizations (e.g. , New Brunswick Dept. of the Environment, Maine Department of Marine Resources, Massachusetts Coastal Zone Management). Through the National Office for Integrated and Sustained Ocean Observations (IOOS: Ocean.US) and the NSF ORION program, advances are being made toward the establishment of a formal system for organization and coordination of observing data collection for the U.S. coastal ocean, including the Gulf of Maine.

The expanding databases from the multitude of observing/monitoring time series and the recent movement towards development of an ocean observing system infrastructure for the Gulf of Maine has spurred the need for development of multidisciplinary models for analysis and interpretation of the observing/monitoring data. While the data products themselves can serve user needs, value-added products of models that analyze and interpret observing data will contribute to a more effective, rational basis for management decision making in fisheries and the coastal zone. Among the recommendations of the recent CICOR planning workshop (Anon, 2005) are the development of improved predictive capabilities, built around an integrated model system and the driving of model improvement by sustained observations and comprehensive study of physical and biological processes and variability. The ECOHAB/GLOBEC Gulf of Maine Modeling Workshop held in Portland (Anon., 2002) recommended six tasks for future workshops: (1) identify specific problems (i.e., "realistic" model products that would be of interest to both research and management communities) to address, (2) identify where additional observations are needed, (3) specify the criteria on which to judge model accuracy, (4) determine the best ways to present and access model output, (5) determine the most useful types of forecasting systems, and (6) discuss long-term transition issues.

This RARGOM theme session builds on the foundation of the discussions and recommendations from these workshop reports as well as from previous RARGOM theme sessions, workshops, and meetings associated with other regional programs. Assessment of modeling needs in relation to the regional observing system involves, among other issues, consideration and understanding of the impacts of change due to environmental forcing at multiple time scales, including, for example, bottom-up impacts of climate forcing on Gulf of Maine ecosystems and direct environmental impacts resulting from changes in physical forcing.

The meeting objectives were set out to appeal to the broad range of interests of the meeting participants. They focus especially on refinement of questions defining research and specific user needs and development of capabilities of integrative models to address these needs for the Gulf of Maine, including the identification of where additional observations are needed. The workshop objectives were addressed in the plenary sessions and working group discussions. There were three major topics:

1. **Identify management issues that can be addressed by multidisciplinary models within the framework of a regional observation/modeling system and processes for linking management needs**

with modeling capabilities. Are the models meeting the needs of managers? Are there new ways and organizational processes that could bridge the management and modeling communities at a regional level? What specific questions about the Gulf of Maine system are of interest to both the management and research communities and can be realistically addressed by the models? What sort of output would help resource managers with effective decision-making? What are the needs for coupled physical-biological models that include climate and environmental change among the stressors and forcing factors relevant to fisheries and coastal zone management issues?

2. **Describe the status of integrated modeling for the Gulf of Maine system and identify the critical issues and research priorities for model development.** What are the present capabilities of the physical, coupled physical-biological and ecosystem-based models in relation to needs of users of the observing system? What directions in model development should be undertaken to meet user needs? What are the common, critical issues that need to be addressed to advance development of the models in the Gulf of Maine?

3. **Identify the critical data needs for model development, evaluation and application in relation to the observing system.** Are the observations meeting the needs of these models? What are the most serious gaps in data needs? What advances in data assimilation techniques could be applied in the Gulf of Maine observing system? What adjustments and additions to the observing system should be made?

Plenary speakers at the workshop provided reviews of subjects relevant to the theme from both management and research perspectives. J. Quintrell discussed the relevance of modeling in the context of the regional observing system. D. Lynch discussed the history of and critical issues for Gulf of Maine circulation modeling. The circulation and mixing models are central to the analysis, interpretation and application of observing system data. K. Drinkwater and R. Chen offered, respectively, fisheries and water quality perspectives. D. Brickman provided an overview of modeling and observing systems in the upstream Canadian coastal waters. R. Beardsley reported on the status of physical atmospheric-ocean modeling in the region. D. Mountain provided an overview of observing system data collection and management in the Gulf of Maine.

A special session in the evening of the first day was devoted to developments in coupled physical-biological modeling. P. Wiebe provided an overview of the rhomboid, or middle-out, approach, in which models focused on simulating dynamics of different trophic levels and key species can be linked to provide understanding of variability in climate forcing in marine ecosystems. He described the BASIN (Basin-scale Analysis, Synthesis and Integration) program to study the North Atlantic marine ecosystem as an example of this approach. D. Speirs described how climate forcing on the abundance and distribution of the planktonic copepod, *Calanus finmarchicus*, which dominates the zooplankton assemblage in the North Atlantic and in deeper parts of the Gulf of Maine, can be simulated by coupling a 3-D circulation model to a biological model of the copepod's life cycle. F. Maps presented a coupled physical-biological model for the Gulf of St. Lawrence, developed by M. Chifflet and others at Fisheries and Oceans and the Université du Québec à Rimouski. The model simulates primary production and seasonal spatial variation in chlorophyll biomass for the region.

The workshop was organized by RARGOM in collaboration with GoMOOS, the Gulf of Maine Census of Marine Life and the Coastal Observing Center of the University of New Hampshire, with major funding from the NOAA Center for Sponsored Coastal Ocean Research.

Executive Summary

RARGOM convened a workshop on the theme of modeling needs in relation to the emerging regional observing systems on July 6-7, 2005, with funding from the NOAA Center for Sponsored Coastal Ocean Research. The workshop objectives were to identify (1) priority management needs that could be addressed by multidisciplinary models which use observing system data, and ways to link these needs more closely with model development, (2) critical issues for moving regional multidisciplinary modeling forward and (3) critical data needs for model development and applications. The broad sweep of these objectives brought together resource managers and marine research scientists from many disciplines.

The discussion themes follow up on a series of workshops that have been held in the region since 1990 (see Appendix A). A sense is building that, while these episodic workshops play a role in fostering communication in the Gulf of Maine community, they are not sufficient to provide regional coordination. Mechanisms are needed to bring powerful but complex research models from their development through the transition to application. Regional coordination is especially needed now, given the momentum to establish comprehensive coastal ocean observing systems in the face of both regional and global change. A large part of the meeting was therefore devoted to the discussion of new ways or new regional infrastructure that would develop and facilitate the application of multidisciplinary models for analysis and interpretation of physical and ecosystem processes using multiple data sources.

Working group discussions identified four types of modeling applications to address user needs:

1. Fine-scale simulations of embayment, nearshore and coastal ocean circulation and mixing
2. Coupled biological-physical modeling to assess impacts of land use development and water quality change in embayments and in the coastal ocean, including simulation of nutrient loading and carrying capacity in inshore embayments
3. Simulation of embayment and shoreline erosion and accretion patterns
4. Transport patterns of planktonic early life stages of fish and invertebrates and coupled biological-physical models for understanding the role of inshore habitats in fish/invertebrate life cycles and impacts of environmental variability on recruitment processes

This list reflects the interests and perspectives of the participants. It is therefore is not necessarily comprehensive, but rather builds on the results of other regional workshops. Collectively, these workshops address the ways in which modeling applications can be useful within a management context.

Working group discussions also recognized that, while there are limitations and constraints on the present capabilities of models to meet these user needs, there is tremendous potential to make advances in our ability to interpret and forecast change in regional environments and ecosystems.

Critical issues for development include:

1. Funding regional infrastructure that will allow regional coordination
2. Advancement of models that have experimental forecasts as products
3. Regional coordination of model assessment (e.g., model skill assessment, evaluation of uncertainties, model ensemble approach to predictions)

Data needs for models were identified and fall into four broad categories:

1. Key pieces of information about biological processes that are presently unknown
2. High resolution time series of physical and biological data for model evaluation
3. Strategically-placed fixed time-series stations to observe seasonal as well as inter-annual change in physical and ecosystem variables
4. Data on upstream boundary conditions

Perhaps the most far-reaching discussion concerned how to build a regional infrastructure that would advance analysis, modeling and prediction of observing data in relation to user needs. We can now conceive of, and have in place many of the elements for, a regional model system (see Fig. 3.1??) that links regional atmospheric models to regional and then local coastal ocean models. Meeting participants discussed the roles and activities of a regional consortium for data analysis, modeling and prediction in the Gulf of Maine. The mission of this regional consortium would be to: (1) facilitate regional model evaluation, assessment, and sharing of knowledge and skill levels, (2) serve to link data analysis, modeling, and prediction capabilities to specific management needs in the region, (3) facilitate coordination among government agencies and universities, and (4) develop and demonstrate environmental analysis and forecast products that could be implemented operationally by government agencies. It was clear from workshop discussions that the present regional infrastructure was inadequate for carrying out the activities needed for this mission.

Two separate, but not necessarily mutually exclusive, organizational structures to fill this gap emerged during working group and plenary discussions. One is a Regional Modeling Center within the Regional Association for the Gulf of Maine Observing System (part of the Integrated Ocean Observing System or IOOS) that would have a role in exchange/transitioning activities to facilitate and provide support for modeling applications to specific management needs. The other would be the establishment of a Gulf of Maine Experimental Environmental Forecast Center, which would foster collaboration among NOAA operational and research centers, the Gulf of Maine Observing System, universities, state agencies and the private sector. Its primary objective would be to develop and test forecast models for the Gulf of Maine that could be adapted by NOAA or other government agencies for implementation in operational mode. The facility would have multiple components, including interfacing with the Gulf of Maine Data Partnership, a test bed computer facility for development of forecast models at various scales (river, estuarine, coastal and regional), outreach and products for users

The meeting participants conveyed a feeling that the timing is right for establishing a regional modeling center that would provide experimental forecasts and transition research modeling to user applications. The U.S. Commission on Ocean Policy calls for a regional approach to stewardship of regional ecosystems and for creation of new structures for addressing regional concerns. The Gulf of Maine region has made significant advances in the development of an observing system for the Gulf of Maine. Regional modeling capabilities have expanded to the point where a regional model system that links physical forcing to ecosystem structure and function is now a feasible reality. Forecasting and predictions, as well as hindcasting for understanding what has been happening in the Gulf of Maine, are seen as possible. Moreover, failures, while expected, will get smaller in frequency and magnitude with future refinements in the modeling and data evaluation process. The feeling at the meeting was that now is the time to "just do it".

A closer connection between the observing system, modeling and management will result in the development and application of new information and analysis tools for rational stewardship of the Gulf of Maine. The potential economic benefits of a stronger and more organized connection between management and research communities are enormous.

Plenary Papers

The Relevance of Modeling to Coastal Management in the Context of an Ocean Observing System for the Gulf of Maine

Josie Quintrell
Gulf of Maine Ocean Observing System, Inc.

<to be submitted, Jim Manning's summary based on notes from P. Wiebe and R. He appears here>

Josie Quintrell led off the workshop with many statements that were repeated in the subsequent talks. She noted the importance of predictive capabilities in addressing a wide range of issues that confront coastal managers and the variety of managers at many different levels. She noted it is often necessary to conduct a one-on-one approach to problems since each situation requires a different set of data and methods. There continues to be a gap, she notes, between the managers and the scientist since they are not driven by the same incentives and have different time constraints. While the managers would like a desktop tool developed for their individual pursuits to satisfy legal issues in a limited time frame, the scientist often prefers to focus on open ended, longterm, process- oriented investigation. She suggested that this gap be filled somehow. Perhaps scientist have been asked to fill the wrong role and that another sector (possibly the operational ocean observing and the private sector) should be asked to join the effort and fill the gap between managers and scientist.

Questions were raised about the potential role of the private sector. Is there interest (Janet Campbell) and are the models developed sufficiently (Michele Dionne) to be used as credible tools? A few other questions addressed the funding in the past (Mountain) and the future (Turner) and it was agreed, as usual, that the science needs to focus more on the user's needs and manager's concerns. Josie noted that the private sector may fill the gap for industry's interest (oil &gas, navigation) but not that of the state coastal managers.

Gulf of Maine Circulation Modeling: Prospects for Skill and Critical Issues

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Background

At the outset of this conference, we need to establish some known or 'self evident' things on which to build. Relative to circulation, there is a well-established set of equations with known solutions and properties. Further, there is a well-established set of algorithms that solve these. That there is a lot of room for improvement, no one disputes. But it must be agreed that these equations and algorithms are adequate to the task before us. All of this status-quo capability stems from academic work, vetted in peer-reviewed literature. On practical machines, resolution - both of data and of computation - limits performance today and is likely to do so for some time. But the general pattern of "canonical physics coverging" on the physical environment in which organisms live, is established today and can be realized operationally. Nevertheless, it remains an illusion to talk of a comprehensive state-space description of "ecosystem", adequate for all problems. Hence, analysis is likely to proceed for some time with the biotic parts of problems being formulated on various simplified phenomenological bases, supported by a realistic simulated abiotic environment. It is appropriate to discuss circulation skill against this backdrop.

The spatial scale of circulation physics is well-established, beginning at least with Bigelow and permeating all recent science programs -- RMRP, GLOBEC, EcoHab, etc. Those that start with smaller spatial coverage, invariably end up with larger domains of interest, significantly extending “upstream” into the Bay of Fundy and over the Scotian Shelf. It is clear that this domain represents multiple regulatory overlaps.

Data over this domain is typical of oceanography: it is necessarily sparse relative to the 4D state-space of concern. While motion is generically understood in terms of operative physical principles, oceanic data represents a totally incomplete, but necessary, sampling of real events. It is site-specific and event-specific, sampling particular realizations of generic physics. Data by itself is hopelessly incomplete.

Model simulations are comparably incomplete, but in a different sense. Formally, simulations are available *only* when necessary and sufficient data can be applied to them: initial and boundary conditions, forcing functions, parameters – all over the complete space-time domain of relevance. These constitute the classic well-posed problem in mathematics, which underlies all simulation methods. It is clearly true that there is no well-posed problem in real ocean science, insofar as necessary and sufficient information are never strictly available, and have to be made up, estimated. Worse, the available data, which may seem overwhelmingly abundant, requires quality control in an operational mode that implies prior knowledge of its statistical properties.

Thus we have various instances of the classic “ill-posed problem”, sometimes “ill-conditioned” in various ways, too. Within operational oceanography, these difficulties present themselves on a daily basis. Formal methods of data assimilation are a way around these illnesses.

Data Assimilation

As used here, data assimilation indicates formal methods for solving ill-posed problems through rigorous, statistical use of observation. A generic problem is to make the best use of available data, in terms of the *skill* of the resulting simulation; and to talk sensibly about the skill added by new measurement ideas. By *skill* we mean explaining and predicting what is basically unknown and cannot be know with certainty – the real ocean. There is a formal mathematics of this, just as there is a formal mathematical description of circulation physics. The language includes familiar costructions of the general "State Estimation" problem: Forward and inverse problems, statistical estimation, hindcast, forecast, nowcast, error estimation and error growth, prior and posterior solutions, filtering, adjoint models, Lagrange variables, Jacobians. Much of this apparatus is inherited from other mathematical disciplines and is being actively incorporated into operational oceanography today.

We thus have a merger of several critical disciplines in operational oceanography: ocean science itself; simulation and numerical analysis; computer science; applied statistics; and observational technology. This blend is with us, to stay. What is not so readily acknowledged, is that **people are the key to progress**. Specifically, people who are active at this nexus of interdisciplinary, mission-focused activity. Their care and feeding is a necessary ingredient in any successful operation.

The Platform: Persistence

A modeling center needs a “platform”, crudely, a working computer system, software and network. It must persist on timescales comparable to the problems which it seeks to address. Here these are decadal at least. It is simple, but wrong, to think of this in hardware terms. The lifetime of individual machines is only roughly 2 years – due to obsolescence and loss of serviceability, not loss of basic hardware function. Individual projects work on a 3-year timescale, after which they are over and ideally archived and the PI’s are gone. Operating systems persist longer, maybe 5 years. (Here we consider parallel architectures, the mix of personal and central computers, etc.) Longer than any of these, is the persistence of **people and ideas.** Of course ideas last indefinitely, but not if properly conserved by, and used by, people. So the key to persistence of the operational platform is finding and keeping a functioning cohort of professional people. As above, the people factor emerges easily as a fundamental constraint on operational success. All of the maxims of good management pertain here: aim high, expect to succeed, learn from failure, practice subsidiarity, avoid dictating solutions and ideology, encourage and respect the individual creativity. Clearly, machines are not the “capital” of the system; people are.

Resolution Matters

Current applications are capable of resolution at 100’s of meters, *and it matters*. While all models are “converging” on the same underlying continuum, we are not there yet due to practical limits on resolution. Any approaches that allow improved resolution, are capable of contributing insight and progress.

Related, *data resolution* matters, too. A mismatch between the spatial scales measured, and those represented in a simulation model, results in model-data misfit statistics that are necessarily bigger that simple observational noise. The simple example of velocity data is useful. Local measurement of V will reflect very local bathymetry, never resolved by contemporary models. Both direction and speed will be biased, and lacking the bathymetric realism, models will have to expect larger discrepancies due to this.

Adding more measurements and averaging, turns individual biases into apparent noise in addition to simple measurement noise. So, both model and data resolution needs careful attention.

Data assimilation procedures in themselves are *not* a fix for poor resolution. Data assimilation can make matters worse when done right – that is, data can be inadvertently 'fit' to discretization error. Two wrongs don't make a right, but they may appear to. Hence, there are two necessary frontiers of progress, data assimilation *and* resolution.

In the examples, I illustrate some of the Dartmouth applications to Georges Bank, the Gulf of Maine and Maine Coastal Current, the South Atlantic Bight, and the Western Irish Shelf. Throughout all these examples, there are some themes which re-emerge: resolution needs to resolve the local dynamics; spatial and temporal extent need to fit the scales of motion which can be forced; and careful and statistically valid data assimilation can go far in delivering skill. All of these applications can be viewed on the web[i].

A Decade of Recommendations

We do not lack for recommendations about the need and potential function and benefits of a Gulf of Maine Modeling Center. The second RARGOM workshop in 1993 made the relevant baseline recommendations.[ii] They have been distributed with the conference materials today. A review of these findings reveals that *they are still right and relevant today*. The writers then were broadly accomplished at their trade, and the issues discussed persist. I would not change those recommendations now.

In the intervening twelve years, what has happened? A president has been impeached, the leadership of the Palestinian Authority has changed hands, the United States has gone to war twice, and a Pope has died and been replaced. Closer at hand, many of the 'recommenders' from 1993 have moved on to investigate other waters and left their work in journals or on web sites; and several subsequent conferences have made numerous corroborating recommendations. But, there is still no realization of a Gulf of Maine Modeling Center.

This is an *organizational problem* with which we are all familiar. Rather than speculate on 'why', I offer a different question: How would the region recognize a modeling center if/when it had one? What are its properties and activities? What are the metrics of quality and success?

Qualities of a Center

A productive center will have certain features:

1. Archive of relevant material to forecasting the Gulf of Maine:
   a. Data
   b. Software
   c. Reports and Papers
   d. Data Standards
   e. Simulation Results

   This archive should function as a resource for the region and gain the respect and use of the scientific communities for the Gulf of Maine and other regions as well.
2. Active electronic link to major software archives (e.g., LAPack, TICOM) and maintenance of a set of projects contributory to them.

3. Users Group – working scientists who use and contribute to the Center in their own projects, meeting periodically.
4. Sustained contribution to research in the Gulf, as measured by peer-reviewed contributions by User Group members active in major agency research programs.[iii]
5. Board of Overseers – distinct from the Users' Group, this external Board needs to concern itself with funding, science and operational direction, performance evaluation, end product delivery and outreach.
6. A concept of modeling and forecasting as its own 'science', a fundamentally interdisciplinary activity, subject to experimentation in numerous other venues. In this respect, a scholarly view of the contributions of the long line of excellent scientists who have gotten us this far, is necessary if the activities of a Center are to persist. The list is long, and very interdisciplinary.
7. Staff and supervision of the highest quality. The permanent staff must be co-located somewhere. There is little precedent for a totally distributed group. Personal interactions still matter greatly. The quality of supervision, the expressed goals, the dignity of the scientific mission – these all need constant attention.

Organizational Recommendations:

We must recognize the importance of organization in making progress. I offer a few recommendations:

1. Invent no new political organizations or agency acronyms
2. Instead, institute an Interagency Agreement to support and use the Center. Insist on Center standing in all relevant science and regulatory communities.
3. Use the Interagency Agreement to
   a. Spread the cost among agencies
   b. Coordinate service to diverse populations: Science, Engineering, Management
   c. Secure internal agency staff participation
   d. Require PI participation in the Center as a precondition to agency-sponsored work in the region
4. Among participating agencies, contribute staff the Users Group and the Overseers' Board
5. Avoid distorting the University Mission. Its natural tendency is toward basic science. Preserve that mission; it is necessary. But, require a new operational mission to proceed in parallel, one naturally responsive to service interests.
6. Expect to Pay and Get

Finally

As we plan for the formation of a Center, I think we can agree on many things which are necessary to a) retain the best talent, b) do first-rate work, c) satisfy the operational needs, and d) engage the various interested communities. Certainly, we can all agree on one thing: failure is not an option in this venture.

Notes

[1] Internal Reports of the Numerical Methods Laboratory, http://www-nml.dartmouth.edu/Publications/internal_reports/

[1] Peer-reviewed publications of the Numerical Methods Laboratory, http://www-nml.thayer.dartmouth.edu/Publications/external_publications

[1] *Gulf of Maine Circulation Modeling: Workshop Proceedings*, RARGOM Report **94-1**, E. Braasch, ed.

[1] An example GLOBEC program list, covering a decade of contributions by US and Canadian scientists, can be found at http://www-nml.dartmouth.edu/Publications/internal_reports/NML-05-5/Globec_Cumulative.html

Incorporating Fisheries Oceanography into Ecosystem Based Management for Fisheries

Ken Drinkwater
Institute of Marine Research
<to be submitted, Jim Manning’s summary based on notes from P. Wiebe and R. He appears here >

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Ken Drinkwater focused on the ecosystems approach to fisheries where social, economic, and political factors are important. He reiterated the call to begin the process of generating a predictive capability despite not understanding of **all** the factors. As long as we provide probabilistic uncertainties with our projections, we can always strive to subsequently reduce the error fields. He noted this is an “evolutionary” process more than it being a “revolutionary” process. Since we are never promised much more funding, we need to take baby steps to our goals, collect both old and new datasets, and rely heavily on modeling aspects. Models should be used to conduct sensitivity analysis. The “type of understanding” we gather from valuable longterm datasets changes as the dataset grows. After some examples of cod, capelin, tile fish, and shrimp, he noted the importance of attempting to differentiating human and environmental forces. In the first case, northern cod for example, reduced in size from 1961 vs 1991 which had a negative effect on spawning while, at the same time, fishermen were dumping small fish to catch larger (“highgrading”). Ken then went on with more examples of fisheries oceanography in Norway including works by Budgell and Huse.. He finished with a list of items “to do next” including fast-tracking model efforts, focusing on models w/biological aspects, conveying the uncertainties, looking at more zooplankton-fish relationships, encouraging multidisciplinary teams, and putting more effort into criteria for evaluating models.

Coastal Management Issues from a Water Quality Perspective

Robert Chen
University of Massachusetts Boston
<to be submitted, Jim Manning's summary based on notes from P. Wiebe and R. He appears here >

Bob Chen presented a summary of water quality and specifically what "water quality" means. It turns out to mean a lot of things. It is a complex combination of variables that fortunately can be watched with a variety of simple indicators (p.e. Rapid colilert and DNA microarrays). He demonstrated the new technologies under development at UMASS Boston and elsewhere allows investigators to "snoop" around (~8 knots on ECOSHUTTLE) as "urban oceanographers" to detect anthropogenic inputs to the marine environments. One example that many of us found very interesting is their finding high levels of caffeine in the NY/NJ waterways. The great advantage of these new flow-through systems is the speed of detection where, for example, levels of "pyrene" is detected in the matter of seconds. Other notes included the importance of getting a highly-resolved physical model correct, GIS, involving stake holders, involving people with local knowledge, and keeping it simple.

Ocean Observing and Operational Oceanography in Canadian Waters

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Dartmouth, Nova Scotia

This presentation makes three points. First, the Gulf of Maine is part of a larger North Atlantic circulation system influenced, amongst other effects, by the NAO. Second, data streams are being collected by Canada's Atlantic Zone Monitoring Program. Third, there is an operational oceanography initiative currently underway at the Department of Fisheries and Oceanography (DFO).

Part of a Larger Circulation System

The Gulf of Maine can be considered as the end of the line of a circulation system that is affected by colder currents emanating from the north that wind their way into the Gulf (the Nova Scotia coastal current and the shelf break current) and the warmer Gulf Stream to the south. Research at the Bedford Institute of Oceanography is pointing out a connection between these currents and the NAO. When the NAO is high there are more cold air outbreaks over the Labrador Sea, and this results in colder temperatures on the Newfoundland Shelf, in the Gulf of St. Lawrence and on the eastern Scotian Shelf. At the same time, the transport of the cold Labrador current is reduced as it follows the shelf break around the Grand Banks, resulting in warm shelf break water filling the central Scotian shelf and other deep basins farther downstream. The reverse occurs for anomalously low NAO's, as was seen in the 1998 event where cold Labrador waters penetrated the Scotian Shelf and the Gulf of Maine. These environmental influences are found to affect the distribution of fish species on the eastern seaboard of North America.

Atlantic Zone Monitoring Program Data

The Atlantic Zone Monitoring Program was implemented in 1998 and is an ongoing DFO program. Its goals are to collect and analyze the biological, chemical, and physical field data that are necessary to:

1. Characterize and understand the causes of oceanic variability at the seasonal, interannual, and decadal scales
2. Provide multidisciplinary data sets that can be used to establish relationships among the biological, chemical, and physical variables
3. Provide adequate data to support the sound development of ocean activities

Its sampling strategy is based on:

1. Seasonal and opportunistic sampling along sections to quantify the oceanographic variability in the Canadian NW Atlantic shelf region
2. Higher-frequency temporal sampling at more accessible fixed stations to monitor the shorter time scale dynamics in representative areas
3. Fish survey (details later) and remote sensing data to provide broader spatial coverage and a context to interpret other data
4. Data from other existing monitoring programs such as CPR lines, Sea Level Network, atmospheric data

Annual bulletins, graphs, and (some) data are available online at:

http://www.meds-sdmm.dfo-mpo.gc.ca/zmp/main_zmp_e.html

The occupation frequencies at the fixed stations (of interest) are: Station 2 (Halifax line) nominally every 2 weeks, Prince 5 (Bay of Fundy) monthly. For the sections: spring and fall at Cabot Strait, Louisbourg, Halifax, BB.

Data collected (in general) are: CTD, chlorophyll, phytoplankton sample, zooplankton tow (200 µm), nutrients, oxygen, fluorescense, light attenuation, Secchi disk. The following data are online:
Biological data: images only, not up to date
Physical/nutrient data: data + images, up to date

Groundfish survey data are also available as a compliment to the Atlantic Zone Monitoring Program. A stratified random survey has been done since 1970 and is easily accessible to certified users. The survey measures groundfish species (+ invertebrates), CTD, plus the same data as AZMP except at lower resolution (e.g. ~30 zooplankton tows in July survey out of >100 trawl tows). There is also a fall snowcrab survey that collects T and S.
The frequency is:
February: Georges Bank
March: Eastern Scotian Shelf
July: Scotian Shelf, eastern Gulf of Maine, Bay of Fundy

A New, Comprehensive, Operational Oceanography Initiative

Currently, there is a new operational oceanography initiative underway at DFO. It is composed of two main streams:

1. Operational Global Coupled Atmosphere-Ice-Ocean Assimilation and Prediction System
   Partners: Meteorological Service of Canada (MSC), DFO, Department of National Defense, universities
   Basic reason: improved atmospheric forecasts
2. DFO Operational Oceanography Initiative
   Related to (1) above
   Northwest Atlantic (NWA) focus with regional emphasis
   Basic reason: search and rescue, oil spills, emergency response.
   Broader mandate: Ecosystem based management

Part of our mandate was to decide upon a common model. This required good leadership (provided by John Loder), and was aided by a circulation model assessment report led by Dan Wright. Both operational streams are to be based on the Océan Parallelisé (OPA) model. This was recommended because of:

- Prior use in an operational system (MERCATOR)
- Available data assimilation routines
- Nesting capability
- High level of support (model is becoming the European standard)

The Global stream (MSC) will be fast-tracked using the Océan Parallelisé (OPA) model coupled to the Canadian Global Environmental Multiscale (GEM) atmospheric model, on a 3-5y timescale. Ultimately MSC may switch to wet or aqua GEM, which is in development.

The Northwest Atlantic basin domain will get its boundary conditions from the MERCATOR system. Nested within the Northwest Atlantic domain will be higher resolution shelf domain(s). The planned horizontal resolutions are: 10-20 km for the Northwest Atlantic domain and 2-4km for the embedded shelf domains.

Our goals for 2005-2006 are:

- Installation of initial ("fast track") global OPA at MSC
- Test efficiency and basic utility of OPA for Northwest Atlantic
- Implementation of "spectral nudging" technique (K. Thompson, D. Wright and others, in prep) in NWA OPA
- Learn technology for embedding of finer resolution regional models.
- Assess OPA on shelf domain.

In the longer term, we plan to use the shelf operational system as a basis for ecosystem models for Atlantic Canada.

Coupling Basin Scale to Gulf of Maine Models

Bob Beardsley
Woods Hole Oceanographic Institution
with contributions from
Ruoying He, John Kelley, Changsheng Chen, Jamie Pringle, Ken Drinkwater, Dale Haidvogel

We consider in this talk some of the key issues in using basin-scale ocean circulation models to provide accurate boundary conditions to drive regional-scale coastal ocean circulation models, with a specific focus on the Gulf of Maine and adjacent New England and Scotian Shelves. In general, a regional model needs specification of current, water properties (e.g., temperature, salinity), and surface elevation along its open boundary, freshwater input along its coastal boundary, and surface momentum, heat, and E-P fluxes over its surface boundary. The surface forcing can be estimated with sufficient spatial and temporal resolution using a regional meteorological mesoscale model (e.g., MM5 or the new Weather Research and Forecast (WRF) model). Due to the large computational and human effort required to run basin-scale models in a nowcast-forecast mode, the best approach at present is to extract through interpolation the ocean boundary conditions needed for the regional model from an existing basin-scale ocean model. This 1-way nesting approach ignores feedback from the regional model to the larger-scale model and allows different types of coastal models (both structured grid (e.g., POM, ROMS) and unstructured grid (e.g., FVCOM) to be easily nested within larger-scale ocean models with different horizontal and vertical grid structure.

At present, operational models for the North Atlantic basin include the French MERCATOR and NCEP/Miami HYCOM models. Canadian and Norwegian scientists are developing separate OPA and ROMS basin-scale models, respectively. Of these four, HYCOM appears to be better suited for application to the Northeast US (including the Gulf of Maine), and one example of successful HYCOM-ROMS nesting is presented. What is needed next is a rigorous assessment of (a) the abilities of these basin-scale models (especially HYCOM and MERCATOR) to reproduce circulation/water properties in the extended regional domain (e.g., does the model reproduce GS variability and production/movement of GS rings?) and observed current/water property events (e.g., 1998 GB freshening) and time series of currents/water properties observed using moorings and sections near regional model ocean boundary (e.g., Halifax line) and (b) the relative importance of ocean boundary condition information on processes of importance/focus in a coastal ocean model (e.g., is GS position important for storm surge prediction?). Canadian scientists have several recent data sets that they plan to compare with MERCATOR reanalysis results, however, we suggest that RARGOM/NOAA foster such assessment activities by establishing a working committee to monitor developments and organize periodic workshops that bring together both the regional scientists working on the assessments and elements of the operational modeling community to discuss progress, future developments in the operational models and potential collaboration and input into operational model improvements. Lastly, we suggest that an experimental regional forecast center be established in collaboration with NOAA (and Canadian scientists) to start producing fore-, now- and hindcasts. This will require the use of basin-scale models to provide the boundary conditions in the regional modeling and speed the assessment and ideas for improvement.

Observations and Data Access

David Mountain
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NOAA Northeast Fisheries Science Center

The Gulf of Maine Ocean Data Partnership (GoMODP) was formed to promote and enable the sharing of marine data in the Gulf of Maine region. Established through a Memorandum of Understanding, the Partnership currently has over twenty members representing most of the major data collecting organizations in the region, including state, federal, and academic entities in the United States and Canada. The Gulf of Maine Ocean Observing System (GoMOOS, Inc.) is the host of the Partnership.

Successfully sharing data involves three criteria; the data must be (1) discoverable, (2) accessible, and (3) interoperable. A major goal this year for the Partnership is to have all of the partners register their datasets with the appropriate metadata at one of the major data clearing houses, either GeoConnections or the Global Change Master Directory (GCMD). These datasets then can be ‘discovered’ by potential users. To make datasets accessible, the intent is for partners to serve their data through one of the established internet data-sharing protocols. Two of the more popular protocols are DiGIR, which is being used by OBIS and the Census of Marine Life, and OPeNDAP, which was developed for the U. S. Integrated Ocean Observing System. Interoperability refers to the ability of different, distributed data sets to be successfully and meaningfully brought together for use in an integrated manner. GoMOOS, working with other partners in the region, has undertaken a number of projects to develop web-based tools that allow the interoperable used of distributed data sets. Over time, the Partnership expects to promote the development of more such tools to meet the needs of data users in the Gulf of Maine region. It is hoped that the data sets made available through the Partnership can supply the operational data needs of future modeling activities in the Gulf region.

Coupled Physical Biological Models and the Observing System: the Rhomboid Approach

Peter Wiebe
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<to be submitted, Jim Manning's summary based on notes from P. Wiebe and R. He appears here>

Peter Wiebe started out with some discussion on the NAO's effect on wind. When the pressure gradient is high, the wind/current moves towards GoM when otherwise it is towards Europe. He presented an example of the Laborador Seawater incursion into GoM due to the negative NAO event of 1996 (??). Throughout his talk he highlighted the sequence of physical conditions affecting the chlorophyll which affects the zooplankton which affects the larval growth and survival and, therefore, recruitment. He note the **B**asin-scale **A**nalysis, **S**ynthesis and **In**tegration of oceanographic and climate-related processes and the dynamics of plankton and fish populations in the North Atlantic ocean (BASIN) as an example of this approach. The aim is to understand and simulate the population structure and dynamics of broadly distributed and tropically important plankton and fish species in the North Atlantic Ocean to resolve the impacts of climate variability on marine ecosystems and thereby contribute to ocean management. The objectives are 1) integration and synthesis of existing basin-wide data sets, 2) build on the current state of the art in bio-physical modeling, 3) hindcast modeling studies to understand the observed historical variability of the North Atlantic ecosystem, 4) construction of scenarios of possible ecosystem changes in response to future climate variability, 5) identify data gaps that limit process understanding- and contribute to uncertainty in model results and collect new data to fill the gaps and 6) specify and conduct observations and process studies needed to establish population structure and dynamics across the deep ocean and shelves. After noting Brad DeYoung work (Science, V 304, 4 June 2005), Peter concluded that continental shelf and marginal sea ecosystems are affected by basin-scale forcing on decadal scales and cannot be studies in isolation and that advances in modeling marine ecosystem will require coupling numerical formulations across tropic levels that have differing degrees of resolution. We should be embedding these in a basin-scale representation of the physical and biogeochemical environment.

Ocean-scale modeling of *Calanus finmarchicus*

Douglas C. Speirs
University of Strathclyde

The copepod *Calanus finmarchicus* is an extremely abundant species in the Gulf of Maine, and an important prey species for commercially exploited fish. In addition, it has a very widespread distribution and dominates the mesozooplankton over much of the North Atlantic. Its importance in shelf regions notwithstanding, the major population centers occur in deep oceanic sites in the Labrador/Irminger Sea gyre and the Norwegian Sea gyre. It has become clear, therefore, that a full understanding its population dynamics implies being able to construct models at the ocean-basin scale.

Because of challenges associated with the interaction between a complex life history and physical transport over a large and heterogeneous environment, previous attempts at modeling its demography have been spatially and temporally limited. This talk describes a new discrete-time-space Eulerian model which is spectacularly more efficient than established methods. The biological model is driven by a yearly cycle of temperature and transport from global ocean circulation model and by a food field derived from satellite sea-surface colour observations. Its numerical efficiency permits for the first time a full population model of *C. finmarchicus* spanning its entire geographic range. The model can be rapidly run to a quasi-stationary annual cycle and the results assessed against a variety of field data. Confrontation with data from times series and from the Continuous Plankton Recorder (CPR) allows the optimization of unmeasured parameters and the exploration of structural variants in relation to poorly understood aspects of biology. The model is most successful when a constant fraction of each generation enters the overwintering diapause state at the end of the fifth copepodite stage, and when the onset of reproduction in the spring is cued by photoperiod. The results also indicate that an association between temperature and mortality may be responsible for observed differences in seasonality between regions of the North Atlantic. The demographic impact of transport is shown to be limited, but there is nonetheless a high degree of population connectivity over the whole North Atlantic.

Marina Chifflet and Frederic Maps
Department of Fisheries and Oceans Canada
<to be submitted, Jim Manning’s summary based on notes from P. Wiebe and R. He appears here >

Frederic Maps discussed the “Influence of climate variability and change on the ecosystem of the sub-arctic inland seas of Canada: A modeling approach”. He discussed much finer scale, highly resolved grids where observations of moorings, T, S, dissolved oxygen, fluorescence, chlorophyll a , nutrients, zooplankton, benthos, fishes larvae are described and modeled. Much of the focus was on the Gulf of St. Lawrence with an emphasis on both primary and secondary production mechanisms.

Working Group Reports

The Management-Research Connection in Relation to the Observing System

On the first day, meeting participants, representing a broad range of perspectives and interests within the Gulf of Maine community (Appendix C), were distributed into either habitat, water quality or fisheries working groups for afternoon discussion about the linkage between management needs and modeling capabilities. Each group was asked to consider two questions: "What are specific questions of interest to both the management and research communities that can be realistically addressed by models?" and "What processes or enhancements to regional organization could improve the transition from research modeling to application?" A representative from each group then provided a summary of the discussion in a plenary session.

Modeling applications to user needs

In response to the first question, the habitat working group provided the following examples:

1. Modeling to simulate nutrient loading and carrying capacity in the inshore embayments, for decision-making about setting Total Maximum Daily Loads

2. Simulation of embayment and shoreline erosion and accretion patterns, for decision making related to prevention, recovery or restoration of habitat

3. Transport patterns of planktonic, early life stages of fish and invertebrates, for understanding relative importance of habitats to fisheries and for assessing risks of invasive species

All of the above examples require simulation of fine-scale understanding of circulation in near-shore environments as well as advective exchanges between the nearshore and the coastal ocean and connectivity among adjacent embayments. Cross-shelf exchange to assess nutrient loading into the Gulf of Maine is also an important issue. Biological knowledge requirements include life histories of key fish and invertebrate species and processes determining benthic-pelagic coupling in embayments.

The Water Quality working group provided these examples:

4. Fine-scale simulations of embayment, nearshore and coastal ocean circulation and mixing, for decision- making about siting of outfalls of treated wastewater discharge (e.g. off Portsmouth Harbor), aquaculture facilities, golf courses, or other land use development.

5. Coupled biological-physical modeling to assess impacts of land-use change on water quality, including contaminant sources and fates, and biological systems in embayments and the coastal ocean for decision-making related to permitting and overall patterns of land-use development.

The Fisheries Working Group considered the question in the context of information needs of fisheries management councils, the National Marine Fisheries Service and local fishing communities on the subjects of essential habitat, multispecies interactions and ecosystem based management. Within the framework of the observing system, the capabilities of coupled physical-biological models to simulate and eventually forecast impacts on the ecosystem and on key species of climate change, basin scale (e.g. effects of variability in the inflow of water originating from the Labrador Sea) and longer-term variability (i.e., 5-10 years) on recruitment was discussed. It was noted that the development of modeling capabilities for user needs is bidirectional, i.e., applications will become evident as the models become more sophisticated and results become known to the user community. The working group provided the following specific example:

6. Coupled physical- biological modeling to simulate (with the goal of hindcasting and forecasting) variability in recruitment of northern shrimp in the Gulf of Maine. Processes to examine include variability in transport, distribution and retention of planktonic early life stages, bottom-up effects of food availability/ production on survival, effects of longer-term climate forced change. This information would be useful for decisions related to the management of northern shrimp in the Gulf of Maine. Analogous studies of other key species (e.g. cod, lobster, herring) would also be expected to have value to management.

In response to the second question, there was general agreement among all three working groups that the present processes are inadequate for transitioning research development of circulation and ecosystem models to meet the needs of managers. With the advancement in sophistication and resolution of the models comes higher complexity and requirements of considerable depth of understanding for proper application. Models are tools that require training to use and interpret properly. It is unrealistic to expect individuals from either the management community or the research community to step in by themselves to make the transition from research development to application. Funding levels in existing research-oriented programs, either from the National Science Foundation or from agencies, like NOAA or EPA, with marine interests are inadequate to provide resources to the research sector to support the transition activities, nor is there any consistent regional coordination linking research development with user needs.

There was broad recognition of the need for a coordinating structure and technical experts who could serve as "middlemen" to provide training and information to the management community about modeling capabilities, identify user needs and research expertise and then make effective connections between the user and the knowledgeable researcher, and work to make research simulation models "pre-operational" to transfer to the appropriate government agency as either operational forecasting or on-demand analysis tools. The formal coordinating structure that would comprise model expertise and transition staff could be a form of Regional Modeling Center, either as part of the newly formed Regional Association for Ocean Observing or as a new pre-operational forecasting center that would have ties between university researchers, managers and government agencies such as NOAA, NASA and EPA.

The discussion about improvement to regional infrastructure for connecting management to model capabilities continued in a plenary session on the morning of the second day. The collective results of the first and second day discussions on this subject are summarized in Section **4??,** which outlines a rationale, functions and possible organizational structures for regional coordination.

Critical Modeling Issues and Model-Data Needs

On the second day, participants were divided into groups for afternoon discussion of priorities for development of multidisciplinary model capabilities and identification of data gaps in the observing systems. The majority of physical oceanographers gathered to discuss physical circulation modeling. Two other working groups focused discussion on either coupled physical-biogeochemical modeling or coupled physical-population (for zooplankton and ichthyoplankton) and ecosystem modeling. Summaries of these discussions were presented in plenary session.

Physical Circulation Modeling Group

The questions guiding group discussion were:

1. What are the present capabilities of the physical models in relation to the needs of users of the observing systems?
2. What are the common, critical issues that need to be addressed to advance development of the models in the Gulf of Maine?
3. Are the observations meeting the needs of these models? What are the most serious gaps in data needs? What are the recommendations for adjustments and additions (deletions) to the observing system?
4. What are the specific needs of the physical modeling community for regional coordination?

Discussion addressed the four topics, with the largest portion of time spent on regional coordination. With regard to the capabilities of the present physical models, the general conclusion was that the limiting factor is the availability of data rather than methods or tools.

The examination of critical issues was directed toward identifying applications of the physical models, e.g., providing circulation and mixing fields for study of harmful algal blooms, hypoxia, storm surges, search and rescue and water quality questions. Methods (such as assimilation and nesting grids) have been developed and are readily available, but it is necessary to have the proper initialization and forcing data. Highly resolved temperature and salinity fields, for example, are often missing. Without these data, it may not be possible to resolve the baroclinic features for the spatial scale under investigation, regardless of the sophistication of the model system.

Needs for data depend on the specific question and its corresponding time and space scale requirements. It will probably be necessary to establish a few different "levels of data". One level might be a "backbone" set of gulf-wide data that includes basic variables such as temperature, salinity, current velocity, nutrients and meteorological forcing. A second level of data addresses needs for examination of special processes or small regions such as embayments. The data requirements for understanding processes will be different for a particular estuary than for the entire Gulf of Maine. A third level of data will be obtained in a "rapid response" mode for investigation of environmental events, such as harmful algal blooms, oil spills, etc. The use of AUV's, ferrys, fishing vessels and small coastal research vessels (e.g., the R/V Tioga and R/V Gulf Challenger) were identified as critical for acquiring data at this third level.

With regard to regional coordination, the group generally agreed on the concept of a modeling center as more of an "experimental forecast center" that is pre-operational, as proposed by John Kelly. This center would not be charged with the responsibilities and liabilities of a "24/7" operational center, but rather would have the flexibility to "fail" in its forecasts, in order to promote development and refinement of regional model capabilities. It was proposed that a system could be set up in collaboration with multiple branches of NOAA to provide many levels of data and simulations for the Gulf of Maine, similar to what has been done in other regions such as Chesapeake Bay and the Great Lakes.

The multiple components of an experimental forecast system include data streams, test beds for models, outreach and products for users. This latter component includes a variety of products such as web-served gridded fields and graphs. Examples of specific applications are to address user needs with respect to harmful algal blooms, water quality, navigation and storm surge prediction. The outreach component would include training of students and scientists in using the forecast systems, as well as public education. It would also provide a means for interaction with managers and feedback/exchange in addressing relevant issues. The system would not exclude participation by and for the private sector.

The discussion of the "experimental forecast center" concept ended with consideration of "where" and "when". In other regions, similar centers are located in the vicinity of a university or an existing operational NOAA/NWS lab. The time scales initially would be present out to seasonal changes. There would be "demonstration periods" during which the system would be tested before attaining pre-operational status.

Coupled Physical-Biogeochemical Modeling or Coupled Physical-Population (for zooplankton and ichthyoplankton) and Ecosystem Modeling

Guiding questions for the two other working groups were:

1. What are the present capabilities of the models in relation to the needs of users of the observing systems (in broad categories of habitat, water quality, fisheries)
2. Should the rhomboid approach be recommended as a modeling strategy to analyze and interpret Gulf of Maine observing system data across trophic levels?
3. What are the critical issues that need to be addressed to advance development of these models?
4. Are the observations meeting the needs of these models? What are the most serious gaps in data needs? What are the recommendations for adjustments and additions (deletions) to the observing system?

In assessing present capabilities, the biogeochemical modeling group identified a number of physical-biogeochemical models presently operating within the Gulf of Maine research community. These include, but are not limited to, Gulf of Maine and Georges Bank coupled physical-NPZ type models, modeling of harmful algal bloom production and distribution, Massachusetts Bay circulation and water quality characteristics (oxygen, chlorophyll, nutrients, carbon), and modeling of nutrient budgets for the Gulf of Maine. The group recognized that most current models do not meet the needs of users. While a “perfect model”, will not be ready for a long time, simulation of basin-scale/Gulf-wide influences on local processes and capabilities for hindcasting/nowcasting will be available in the near future.

The population/ecosystem modeling group pointed out that present physcial-biological models are able to address a number of population-level problems in Gulf of Maine, such as production and transport of harmful algae, advection and survival of scallop and fish larvae, distribution of *Calanus* as prey for herring and right whales, and perhaps effectiveness of closed areas as spawning habitat. Modeling capabilities are reduced in the nearshore because of the lack of high enough resolution in the models and a lack of understanding of processes that affect transport in the nearshore.

An important research area involves the use of coupled physical-biological models to predict phytoplankton and zooplankton production and effects on higher trophic levels. The models exist or are in development, but are still untried in terms of forecasting. In shallow water regions, the benthos or marsh impacts will need to be included. Physical-biological modeling is applied to other coastal regions (e.g., Chesapeake Bay) and may be useful for simulations of Gulf of Maine embayments. Models developed in Europe (European Seas Ecosystem Model, Deep Green Ocean), especially for the nearshore of the North Sea, may also be applicable.

There is great demand for model products that can integrate existing data sets over some spatial and temporal domain. Some indicators, for example an index of retention characteristics on Georges Bank in relation to recruitment success, can only be obtained from a model. There is a mis-match between scale of sampling and the model outputs and difficulty in validating the models. However, the models can be used to help bridge the gap between sampling intervals. There is also a possibility of using existing data sets to construct a climatology study of processes affecting nearshore systems and these can be used to provide confidence limits on impacts. Using multiple annual outputs of models to describe the probability of events (e.g., external flows into an estuary to predict the likelihood of establishment of invasive species) might substitute for a real-time model.

Nutrient cycling in bays and estuaries and their transport is a relevant issues that ecosystem models in the Gulf of Maine can address, Prediction of the timing of spring bloom may contribute to an index of recruitment into northern shrimp and spring-spawning fish species. The dynamics of invasive species coming into a nearshore area needs to be modeled in order to predict impact on the other parts of the ecosystem. The models seem to be in place to begin to address this kind of event, but it depends strongly on knowing sufficient about the animal/plant biology.

Both working groups advocated systems that link together models of circulation and mixing with models focused on different levels of the ecosystem. The rhomboid approach will link biogeochemical models to higher trophic levels. There may be opposition to this approach because it does not satisfy a mass balance. However, a rhomboid model system could be formulated so that it would be in mass balance if needed, depending on the questions that need to be addressed.

An example of an application of the rhomboid approach would be an investigation of bottom up controls on herring abundance and distribution in the Gulf of Maine. The system of linked models may include a physical-NPZ model to simulate climate forcing on nutrient and primary production cycles, physical-zooplankton life cycle models to simulate changes in abundance of small copepods as prey to herring larvae in fall and of *Calanus* and euphausid abundance and distribution as prey to adults. These components may be linked to models simulating herring recruitment dynamics and feeding behavior. Coupled models could be used to do sensitivity analysis to evaluate how environmental change might effect the populations or changes in fishing mortality. Hindcasting and forecasting of herring distribution and abundance levels may be useful for understanding distribution patterns and behavior of higher predators, such as bluefin tuna, and whales (Humpbacks), other mammals and ground fish. There is a need to incorporate the top predators into the modeling.

While acknowledging that limitations in data, knowledge and computer technology represent constraints on present modeling capabilities, working group participants highlighted the need to move forward with the development of models with forecasting capabilities, even if predictions are likely to be wrong. "Fail forward" is the expression reiterated in the plenary session. There is a critical need for funding infrastructure in the region that will allow for development of models that have experimental forecasts as products.

The activity of experimental forecasting will have several benefits. It will bring together modelers, data providers and managers to identify and bring into focus where models can be applied to regional stewardship. It will highlight what are the relevant gaps and needs for improvements and enhancements to the observing system for data to both parameterize models and evaluate model forecasts. Failed predictions will lead to refinements to model development and to the observing system with the promise of producing more accurate forecasts in the future.

The importance of model assessment activities was emphasized. Data from the observing systems can be used to evaluate model-data fit or misfit. Regional coordination would contribute to the development of quantitative measures, community accepted modeling skill evaluation, and bench marks for model assessment. Multiple models developed by different research teams would serve to constrain uncertainty to users by providing opportunities for statistical analysis and evaluation of sensitivity to data sources (boundary conditions, initial and forcing conditions). An ensemble approach, with multiple models to make same (or similar) predictions, as well as scenario building with different initial and boundary conditions within one model framework should be favored.

Other critical issues identified by the working groups were:

- High resolution modeling and data to understand small scale variability, such as internal waves, shelf-slope fronts, storm forcing, local heat fluxes
- Better bathymetric data for high resolution model
- Fine vertical scale, thin layers, scallops on the Georges Bank, sampling issues and model vertical resolution
- NPZ model parameterization, for which observing system data is perceived to provide a fundamental contribution
- Linking NPZ to more detailed mesozoplankton dynamical models
- The role of silicate as a nutrient in diatom bloom dynamics
- Zooplankton grazing rates, including the role of microzooplankton.
- Effects of short term events, red tide, storms or wind event, upwelling along the coast
- Coupling of water column and benthic biological processes.
- Water quality, heavy metals and other toxins, mercury issue and impact on fish
- How to represent the rest of the ecosystem in the rhomboid or middle out approach that may focus on a few key species at one trophic level. A classical NPZ model may not be necessary; size spectra or size frequency may be used as an alternate approach.

The general assessment was that observations are not, or are only partially, meeting the needs of models. Four categories of model data needs were recognized:

1. There are key pieces of information about biological processes that are currently unknown and therefore cannot be modeled effectively
2. High resolution time-series of physical and biological data from the Gulf of Maine are needed to feed and evaluate models
3. Fixed time-series stations located strategically, e.g. upstream and downstream in the coastal current are needed to observe seasonal as well as interannual change and to acquire data needed for model parameterization. Sampling at fixed stations requires visits by research vessels for zooplankton / ichthyoplankton sampling and ground-truthing as well as moored, *in-situ* instrumentation
4. The importance of observing systems in Canadian waters upstream was recognized for information about boundary conditions

Recommendations for enhancements to data collection include:

- Deep flow fields at several key locations: buoy N (Northeast Channel), Scotian Shelf, Wilkinson Basin and southwest of the Georges Bank

- Fixed time-series stations proposed for off Penobscot Bay in the coastal current, stations off New Hampshire, Mass Bay near GoMoos Buoy "A", and Stellwagen Bank. Use AZMP protocols (but add finer mesh net tows in addition)
- Monthly large scale survey data to serve for model evaluation
- Nutrient and more biological measurements on the existing observing systems, and key locations (fixed stations and listed above)
- Monitoring of dominant zooplankton life histories and vertical and horizontal distributions, particularly at key locations (e.g., fixed stations, Northeast Channel, Scotian Shelf)
- Use modeling studies to improving sampling plans, e.g., the Observation System Simulation Experiment (OSSE)
- Data from process-oriented studies, especially for more rate measurements, such as new and primary production, micro- and meso-zooplankton grazing rates, export flux (sediment traps, 234Th estimates)
- There is a real need for inshore surveys (phytoplankton, zooplankton, ichthyoplankton, temperature, salinity, nutrients, O_2) using small-scale monitoring stations. Need to identify the locations and justify them.
- There is need for vertical distribution data from the deep basins in the Gulf of Maine, especially zooplankton such as *Calanus finmarchicus*, on a frequent time frame. A combination of OPC, VPR, and vertically stratified nets tows are needed to provide information in near real-time.

Visions for a Regional Approach to Modeling and Prediction in the Gulf of Maine

The concept of regional coordination of Gulf of Maine circulation and coupled physical biological modeling activities was first put forward in 1993 at a RARGOM workshop about Gulf of Maine circulation modeling. The workshop report (RARGOM Report 94-1: see Appendix A) argued for the establishment of a Gulf of Maine Modeling Center in order to advance development of these models and make models more accessible to the broader scientific and management communities. In the ensuing decade, computing capabilities as well as the power and resolution of circulation and coupled physical-biological models have increased dramatically. Recommendations to establish a modeling center have been reiterated in workshops held in 1996, 2000 and 2004 (RARGOM, 1996; 2000; 2004a: see Appendix A). Other regional workshops (RARGOM 1994; 1995; 1997; 2001; 2004b; ECOHAB/GLOBEC 2002; CICOR 2005: see Appendix A) have also brought together research scientists, managers and other stakeholders to discuss and plan (1) the development of predictive capabilities of circulation and ecosystem models, (2) the establishment of an effective observing system to provide data for the models, and (3) the application of modeling capabilities to meet management needs.

Common threads running through these workshops are the recognition of (1) the potential power of modeling to synthesize a large, multidisciplinary accumulation of knowledge for significant benefit to management and stewardship of Gulf of Maine resources, (2) the need to couple observations to data needs for models, (3) the need to foster ongoing dialog among research, management and resource user communities in order to transition research to application, and (4) the need to define a restricted set of realistic model products that would be of interest across communities.

It is apparent that episodic regional workshops are by themselves insufficient to advance both coordination of the increasingly sophisticated multidisciplinary models and the complex process of transitioning these research models to management applications. Research and management needs have been identified; there is the sense now that future workshops will be "spinning their wheels" in the absence of a regional infrastructure that does more on a regular, even daily, basis to tackle these complex issues. An emergent subject of discussion was how to establish a regional infrastructure that supports the operation of regional modeling center.

Rationale for Action and a Regional Approach

There was a general sense among participants that there is a need to move forward with an organized regional approach to analysis, modeling and prediction of observing data. The Integrated Ocean Observing System (www.ocean.us) implementation plan lists data analysis and modeling as one of the three fundamental components, along with measurements (remote and *in situ* observations) and data management and distribution, to effectively link societal needs for environmental information to measurements in the U.S. coastal zone. However, there are few prescriptive guidelines in the national plan for regional organization and governance of analysis, modeling and prediction. Thus, there is an opportunity for the Gulf of Maine community to pioneer a regional approach that suits its particular needs and strengths.

Over the past decade, modeling capabilities have improved dramatically due to the confluence of advances in computer technology and knowledge in ocean physics, biogeochemistry and ecology. We can now conceive of a working regional model system (e.g., Figure 3.1) that links regional atmospheric models to regional and then local coastal ocean models. While Figure 3.1 refers to the linking of atmospheric and ocean physical processes, quantitative understanding of biogeochemical and population dynamics processes can be coupled to the physical models, opening the potential to address of variety of management-related concerns. Some of these concerns were outlined in the working groups at the meeting, for example, the siting of water treatment outfalls or aquaculture facilities, impacts of land-use changes on water quality, variability in nutrient loading and ecosystem productivity, transport and fate of larval fish and tracking of invasive species (see working group sections).

Development of the regional model system is hampered by a lack of regional coordination. A number of institutions conducting research in the Gulf of Maine are developing and implementing regional coastal ocean models at various scales and addressing various questions. There is not any one "best" model, rather there are different kinds of models to serve different purposes, and the regional model system shown in Figure 1 represents a framework of model structure, into which a number of coastal ocean models could be fitted. The regional research community needs to coordinate and facilitate research about common issues, including optimizing data acquisition from observing systems for model evaluation and prediction, model comparisons, data assimilation and analysis, skill development and data sharing. The management needs to develop applications of model advances to real problems and challenges for the stewardship of the Gulf of Maine and its resources; in essence a regional facilitation that adapts and translates knowledge to suit specific management needs.

Considerable discussion during the workshop was devoted to roles and activities and administrative structure of a regional "center" or “consortium” that could fulfill the emergent needs of the Gulf of Maine communities.

Roles and activities of a Regional Consortium for Data Analysis, Modeling and Prediction

The mission of the consortium would be to support development and application of data analysis, modeling and prediction in the Gulf of Maine by: (1) facilitating regional model evaluation and assessment and sharing of knowledge and skill levels, (2) serving to link data analysis, modeling and prediction capabilities to specific management needs in the region, (3) facilitating coordination among government agencies and universities, and (4) developing and demonstrating environmental analysis and forecast products for users that could be implemented operationally by government agencies.

The workshop participants identified a number of potential functions and technical services that the regional consortium or center could undertake to fulfill its mission. A listing of these activities under four broad categories follows. Many of these activities reflect conclusions and recommendations made at previous Gulf of Maine workshops (Appendix A).

1. Model and product development
    - Support and facilitate exchange and resolution of common issues facing regional modeling efforts, including model validation, assessment of model accuracy, limitations on skillful prediction, field testing, and identification of key data needs
    - Facilitate communication among models, e.g. a commonly agreed upon grid (nested scales), model interface standards to enable different physical and biological elements to be interchanged
    - Fund projects that link model development to user needs. The goal is not only to provide valuable user products, but also model research with potential application to user needs
    - Provide experimental predictions with regular deliverables. Focused on certain forecasting products
    - Demonstrate applications. Once model or model system is pre-operational, it could be transferred to a government agency with capacity to provide continuous maintenance and ensure reliability
    - Encourage and provide rewards for applied research that isn't rewarded in academia
    - Oversee RFPs (requests for proposals) for pilot projects to test model applications, for example transferability of models between embayments

2. Knowledge transfer/transition activities.
    - Provide staff support and funding for model transition activities (workshops, consulting, model facilitation to user activities)
    - Build awareness of and trust in models among stakeholders. Identify specific user needs and corresponding modeling expertise in research community
    - Facilitate successful research-manager partnerships for model development applied to specific user needs. Bring together in workshop settings managers with specific need and appropriate researchers and modelers. Facilitate follow-up to ensure that need is met
    - Develop desktop decision support tools and have a training program within a Modeling Center
    - Provide expertise for interpretation of the output and its correct application
    - Facilitate solutions for manager problems, answers to questions and information relevant to decision-making
    - Offer workshops aimed at particular problems, for managers, researchers, modelers
    - Provide access to research scientists to interpret/translate key processes, including financial resources to enable scientists to participate in applied scholarship, technical and advisory roles

3. Access to research products
   - Provide IT services that allow hook-in to regional data/model products, e.g. model flow fields and model input data (bathymetry, winds, river flow, etc)
   - Provide user access to computing facilities as needed.
   - Provide IT services to allow non-technical access to regional data/models
   - Provide an inventory of Research Products, Predictive capabilities

4. Regional coordination
   - Contribute to the integration of data and analysis from Gulf of Maine Observing systems, including NOAA, NSF Orion, NASA remote sensing and IOOS data collection systems
   - Serve as an advocate to bring funds into the region

Organizational structures

It was clear from workshop discussions that the present regional infrastructure was inadequate for carrying out the activities needed for regional coordination of modeling analysis and prediction and for development of data products and tools that have demonstrated utility for the management and stewardship of the Gulf of Maine. There is an inadequate connection between the management/user and research communities. The pressing, day-to-day demands of decision-making associated with carrying out regulations and the equally relentless demands on scientists to sustain research in a highly competitive funding climate leave little time or resources for effective interfacing between the two communities, despite the obvious benefits for the region. Two separate but not necessarily mutually exclusive organizational structures to fill this gap emerged during working group and plenary discussions.

Regional Modeling Center: a role for the Regional Association in exchange/transitioning activities

One of the key missions of a regional consortium is facilitation and funding support for modeling applications to specific management needs. This might include, for example, assistance to a regulatory agency for decisions related to location of sewage outfalls, or aquaculture facilities, impacts on water quality of permitting decisions or setting of TMDLs within carrying capacity limits of an embayment. A new level of regional infrastructure is needed to undertake these transitioning activities. One possibility discussed in plenary session without major disagreement was the establishment of a Regional Modeling Center comprising a project manager and 1-3 engineers/translators/facilitators for carrying out functions outlined particularly in parts 2-4 of the previous section.

It was suggested that such a Regional Modeling Center would not be created as a separate entity, but rather should be part of the Regional Association for the Gulf of Maine Observing System. The Regional Association is an emerging regional organization based at the University of Southern Maine that will have responsibilities for the coordination and operation of the Gulf of Maine component of the Integrated Ocean Observing System (IOOS). It presently has funding to move ahead with the establishment of a governance structure that includes oversight of an Advisory Board comprising representatives from regional groups and government agencies with interests in the Gulf of Maine. A Regional Modeling Center structured under the umbrella of the Regional Association would represent a modeling and analysis component to the regional observing system.

The Gulf of Maine Experimental Environment Forecast Center

During the final plenary session, the concept of a Gulf of Maine Experimental Environmental Forecast Center was discussed. This center would have a primary function of fulfilling the model and product development components (i.e. Part 1 in the section above) of the regional mission. The Center would involve collaboration among NOAA operational and research centers, the Gulf of Maine Observing System, universities, state agencies and the private sector. Its primary objective would be to develop and test forecast models for the Gulf of Maine that could be adapted by NOAA or other government agencies for implementation in operational mode. The facility would have multiple components, including interfacing with the Gulf of Maine Data Partnership, a test bed computer facility for development of forecast models at various scales (river, estuarine, coastal and regional), outreach and products for users (see Figure xxx). One specific goal may be, for example, development of 3D baroclinic circulation models for all estuaries, forced by NOAA subtidal storm surge models and a coastal ocean model at the seaward boundaries.

A key element of a regional Experimental Environment Forecast Center is represented by the word "experimental" in its title. The forecast models that to be developed would have pre-operational status, as compared to "24/7" operational models that have more stringent product reliability requirements and are subject to liabilities for inaccurate results. These experimental forecast models are seen as essential precursors for the development of operational models, in that the experimental forecasting model predictions may be expected to fail. There would be "demonstration periods", where the model forecast system would be tested before it would reach semi-operational status. Insights from the analysis of predictions in comparison with actual observing data would lead to refinements and better predictive capabilities in future model iterations. The experimental forecast models would nevertheless generate products directed to user needs, focusing initially on perhaps 2-3 applications (e.g., water quality issues, predictions of harmful algal bloom timing and distributions, fisheries management).

The outreach component of an Experimental Forecast Center could include training of students, scientists and engineers in use of the system. The Center could develop the capability as well to interact with managers to exchange information and obtain feedback for addressing relevant issues. The Center would not exclude participation by and for the private sector.

Benefits to the region

A closer connection between the observing system, modeling, and management will result in the development and application of new information and analysis tools for rational stewardship of the Gulf of Maine. Previous sections of the report have described specific examples of benefits/products of a regional infrastructure for modeling analysis and prediction to both modelers and managers. Equally important is the potential for users to see new applications and improvements for decision-making as they gain familiarity with the modeling/research capabilities. With the development of forecast modeling, workshop participants envisioned transfer to the general public, for example in the form of local television reporting of changes in oceanographic and ecosystem conditions in the Gulf of Maine, similar to reporting on oceanographic conditions done in Japan. This would raise visibility and understanding of the health and change in the Gulf of Maine and hopefully feed continued interest and support for a strong observing system.

The potential economic benefits of a stronger and more organized connection between management and research communities are enormous. As part of the development of regional infrastructure, there is a need for studies that will quantify the benefits using cost-benefit analysis, in order to reveal the magnitude of the benefit and strengthen arguments for enhancements to regional funding.

Recommendations and Research Priorities

Research priorities for models and data needs (see working group report section)
New transition structure for connecting research and management (see visions section)
A Regional Association center for coastal ocean modeling and transitioning to management
An Experimental Forecast Center affiliated with federal (e.g., NOAA), universities and state agencies

References

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Anon. 2005. Workshop on planning coordinated research on ecosystems, climate and policy in the Northeast". Cooperative Institute for Climate and Ocean Research (CICOR), Woods Hole Oceanographic Institution, and the Northeast Fisheries Science Center (NMFS). January 11-13, 2005. www.whoi.edu/science/cicor/workshop05/report.html

Appendix A: Summary of Recommendations from Prior Workshops

January 2005

Planning Coordinated Research on Ecosystems, Climate and Policy in the Northeast (CICOR/NMFS)

Key Recommendations: (p.1-2)

Assess the horizons of predictability and management, using research to find the limitations on the deterministic and probabilistic models required for forward-looking management strategies.

Establish a baseline for identifying ecosystem change and thus for managing and conducting research in the Northeast by using field surveys, retrospective analyses, facilitated data exchange, and facilities for sample archiving.

Develop improved predictive capabilities for the Northeast, built around an integrated ecosystem model approach, which considers multiple abiotic and biotic factors and assess the role of climate change in comparison with other sources of natural and human change. Drive model improvement with strong likes between sustained observations and comprehensive studies of processes.

Build the Northeast observing system, establishing sustained observations at key sites and broad surveys in the domain and of the estuarine, atmospheric, alongshore, and offshore exchanges within the region in order to provide data required to initialize, test, and improve climate and ecosystem models and management tools.

Conduct comprehensive research studies characterized by high temporal and spatial sampling to address key uncertainties, determine and resolve critical processes, and build improved understanding, parameterizations, and models.

Develop a system for an adaptive approach to management of the Northeast ecosystem resources, with research embedded in the cycle of evaluation and improvement of the management tools and methods and with facilitated flow of data, analyses, and results to managers as well as of management feedback to the researchers.

Foster ongoing dialog among climate, ecosystems, biodiversity, and fisheries researchers, ecosystem and fisheries managers, marine resource stakeholders, the general public, and the NOAA goal teams and program managers to support the adaptive management system, to integrate observations and research results, to effectively disseminate research results, and to guide future observations and research.

• Regular (~every 5 year) broad scale in-situ surveys of the entire region, sampling the planktonic (including cysts) and microbial communities, the physical structures key to modeling (e.g., stratification, currents), the fish stocks, and the biodiversity of the ecosystem by using ongoing broad-scale monitoring, remote sensing, and in-situ resources (satellite, CODAR, volunteer vessel, moorings and buoys, AUVs, gliders). These surveys continue and expand present efforts.

• Observations of the boundaries, better defining the bathymetry and substrate, quantifying the inputs from streams, rivers, and the atmosphere, and measuring the exchanges with the waters to the north (Scotian Shelf), to the south and offshore. This will improve the physical models and better characterize the habitat.

• Improved integration and availability of observations. Creation of a comprehensive inventory of all available data, including ecological information, habitat information, fisheries information, and physical parameters and facilitation of access to all these data to ensure examination of impacts of multiple forcing functions and of all trophic levels.

• Identification and establishment of long-term observing sites where high-frequency variability would be observed, and where nutrients and contaminants, surface forcing, indicator species, and biodiversity would be measured – some as sentinel sites, indicative of change, and as reference sites, providing a contrast to sites with more active anthropogenic and/or natural forcing at work, and for critical in-situ data needed for model assimilation.

• High spatial and temporal resolution observing programs targeting harmful algal blooms, estuarine inputs, and the determination of the balance of processes at the sentinel and reference sites. Several activities need to be fostered in conjunction with addressing these observing priorities. First, the community must be brought together to develop consensus on the choice of sentinel and reference sites and of indicator species. Second, the observing efforts, plans, and evolution need to be coordinated with the modeling efforts; in part this is to ensure that the detailed process study observations are done to identify processes that must be included or parameterized in the models and also to ensure that the broadscale sampling provides the requisite data for initialization as well as for testing and validation. Third, the development of new observing methods must be supported; two examples include, new methods to sustain observations of high-frequency events, and cost effective sampling that provides higher spatial resolution. Finally, the integration of all observing systems across the Northeast must be an ongoing emphasis, include NOAA resources, new resources that the NSF ORION project will develop, NASA and other remote sensing resources, IOOS and regional association platforms, local and state monitoring programs, and volunteer platforms.

Modeling Recommendations: (p.11-12)
Development of an integrated ecosystem model system for analysis of impacts of the diverse forcing functions (e.g., climate change, harvesting, nutrient and contaminant concentration) and as a basis for an ecosystem-based approach to management; this system should link observations, model development and validation, and ongoing use of the system to produce products used for management decisions.
Components Include:
Basin/regional/small scale circulation models(s)
Linked physical/biological models
Better models to manage nutrient inputs to near-shore waters
Models that can be used to investigate cumulative impacts from multiple stressors
Models to improve understanding of prediction and recruitment

Modeling would go on in hindcast, nested, and operational (nowcast and predictive) modes. Initialization and validation requires coordination with research and observations; improved surface forcing fields, the physical fields in the ocean, and nesting to include processes with high spatial resolution are needed, as is work on parameterizations and determining data assimilation needs. Nutrient loading models in embayments and coastal water (with incorporation of benthic algae and eelgrass, better simulation of the light field, and links between primary production and critical resources such as shellfish), population genetics and successional models, larval transport models, recruitment models, and fisheries models (including bio-economic and energy flow/trophic level models that include spatial variability) are specific needs.

Education and outreach recommendations
Improved and ongoing dialog among the managers, researchers, and stakeholders in the climate, fisheries, biodiversity, and policy communities.

Identify the priority elements of the Northeast observing system (agree on key sites as sentinel and reference sites, agree on indicator species, develop enhancements to current repeat broad-scale sampling, integrate and coordinate all possible elements, identify need for new sensors and sampling methods) and the sequence of more intense sampling studies needed.

Assess the coverage of climate and ecosystem issues provided by present models and observations and develop strategies for moving forward integration of all trophic levels and multiple forcing functions.

Initiate program to assess the horizons of predictability, probing limitations on skillful prediction while at the same time identifying key data (initialization, validation), parameterization, and understanding (realistic incorporation of all key physical and biological processes; realistic models of elements of the system) needs, model and parameterization shortcomings, and shortcomings in the foundation of understanding.

Identify the status of archives of physical samples of biodiversity in the Northeast and survey models in use elsewhere in order to enhance current and coordinate future initiatives.
Initiate a working group of researchers (observationalists, modelers, and analysts; climate, ecosystems, fisheries, policy), managers, marine resource stakeholders, and NOAA climate and ecosystems goal team staff

to continue interaction, and to embed the research process in a plan for adaptive management of the ecosystems of the Northeast; repeat the Workshop every two years.

HAB W.G. comments (p.viii)
Form a regional modeling team for HABs in the region, and charge it with the development of a set of regional model products of sufficient geographic scope, time scale, that are inclusive of physical and biological factors that serve multiple sector needs. (Improve existing models and identify new modeling needs).

Nutrient & Contaminants W.G. comments (p.xii)
Physical models are progressing rapidly
Regional and basin models are expected to be available I the next 5-10 yrs.
Progress is being made on biological models but it has been slow
Most models still at the primary production level or there are other models dealing with single species of higher trophic levels. These groups do not seem to get together.
NOAA is funding an eelgrass model.
There is a need to be able to evaluate models to determine if they are good enough to support a particular decision.
What is needed is a validated model that links what is measured to resources. Models need to incorporate new knowledge of climate related changes and help refine TMDL goals n this context.
Improve large-scale modeling, both hydrodynamic and linked hydro-biological models. These models need to incorporate more tropic dynamics if they are to be useful in understanding potential climate change impacts.
Experimental systems such as mesocoms can be used to support modeling activities by defining parameter interactions and for model testing.

Fisheries W.G. comments: (p.xviii)
Develop suites of theoretical models relating ecosystem processes to forcing functions that must be considered as control hypotheses in evaluating key questions (biomass spectrum, N-P-Z , etc.).
Contrast single-species models with ecosystem models re. their implications for management.
Define the data requirements necessary to parameterize candidate models.
Match models with historical data synthesis.
Develop approaches for explaining ecosystem change in the context of candidate models and multiple simultaneous drivers.

Biodiversity Conservation W.G. comments: (p.xxi)
Biological response to environmental and human pressures (can we predict successional stages in particular areas?)
Effect of climate change
Resilience of species
Biogeographic distributions based on other data (environmental past and present)
Joint US/CA effort to link basin and shelf seas models to predict changes in circulation ad mixing leading to effects on biogeographic shifts in distribution of species.
Trophic interactions.

July 2004

Integrated Interdisciplinary Modeling (RARGOM Theme Session notes)

Need to work towards establishment of a regional modeling center
Need to encourage a regionally specific data lab to handle all information – what role should RARGOM serve in the establishment of a center for available data on the Gulf of Maine, esp. important for real time modeling.
Need to establish a single site for data as well as model products.
Need to develop exchange nodes for environmental information.
Data to be made available should be prioritized

Standards are needs for data and model evaluation
How is data and model performance measured?
Characterization of models needed re. strengths, time scale, length scale classifications.

Regional observing and research are complementary, cooperation and interactions between the two endeavors generate additional opportunities.

Real-nearshore research is too site specific – a unifying approach is needed in order to obtain federal funding. Large gaps exist between local coastal monitoring of estuaries and bays – there is a need to bring large observation efforts to the local level to close these gaps.

Need to build a mesoscale atmospheric model of the Gulf of Maine – RARGOM take the lead on developing this

Need to incorporate biogeochemical models into planning as a high priority. Need to develop a clear understanding of the sources and sinks in the Gulf of Maine from a biological standpoint.

RARGOM should play a role in defining the limiting fields for modeling (physics, biology, chemistry?) Need to understand what can/cannot be modeled with current/near-future knowledge

Modeling efforts should be derived from management needs and research questions; RARGOM should lead the efforts to define these questions and identify the needs, serving as the link between various organizations

RARGOM needs to make outreach to the management community a priority; guidelines are needed. Need outreach at regional and federal levels re. describing to others that models are important research tools.

June 2002

Management and scientific informational needs for harmful algal bloom and fisheries forecasting in the Gulf of Maine; A framework for moving toward an operational capability. (Proceedings of the ECOHAB/GLOBEC Gulf of Maine Modeling Workshop)

Management: A list of potential model products needs to be defined that would be of interest to managers. This list can then be used to help define the type of forecast to be attempted (e.g. guidance vs. operational, daily vs. strategic), to determine the level of forecast accuracy and to identify realistic model products.

Model Development: Future development efforts should focus around a core group of models that represent a hierarchy capable of addressing a wide range of management issues. The simulation of near-shore hydrodynamics has to be improved so that problems of interest to coastal managers (e.g. bloom trajectory, larval transport) can be addressed with greater resolution and skill. Any models used for environmental decision-making have to be well documented (i.e. published), tested (i.e. a comprehensive assessment of model accuracy, error and uncertainty) and proven (i.e. success stories) so managers can make informed decisions fully aware of the limitations of model simulation results. A model interface standard should be developed to facilitate the use of multiple models and to allow comparisons between different model formulations.

Model Transition: The interactions between modelers and managers must be maintained throughout the transition process if the full potential of developed model products is to be realized. Forecasting capacity for model products should be developed incrementally to build skill, confidence, familiarity and trust within the management community and public. Proposed forecasts should be supported by cost-benefit types of analyses to demonstrate societal benefits and to justify continued funding. An observational system to support proposed model forecasts that includes regional observing systems, ship transects, and field studies must be expanded upon.

Both HAB and fishery managers need more baseline physical and biological data (e.g. from regional observing system, satellites, ongoing monitoring and regional research efforts). This data is vital to detect environmental and species trends, along with, initialization, calibration, verification, and data assimilation for models. Through long-term, spatially/temporally extensive data sets and biophysical models the extent to which broad-scale environmental factors (e.g. North Atlantic Oscillation, Gulf Stream rings, climate change) affect HABs, phytoplankton, zooplankton, larval survival and growth can be investigated. Additional information on meteorological, oceanography and life history factors should allow for even greater predictive modeling capability. The ability to predict the transport of suspended particles will also be beneficial for tracking contaminant spills (i.e. sewage, oil) and the transport of larval organisms.

There is also a need for a more complex, detailed understanding of ecosystems and multi-species interactions especially for fisheries managers who are often tasked with managing several interacting species.

Managers

What key products could help you do your job better and more efficiently?

The ability to detect environmental parameters with greater detail would be a key product for resource managers. Tracking temperature, salinity, and phytoplankton remotely are powerful tools to monitor changes in the physical environment (i.e. upwelling, fronts, rings), as well as the transport of passively advected particles (e.g. larvae, algae) either directly or indirectly through a passive tracer such as sea surface temperature.

Another key product for resource managers would be the ability to combine environmental data with model simulations to make short- and long-term predictions. Some possible areas for prediction include 1) transport of nutrients, contaminants, HABs, and larvae, 2) the timing, duration, and location of HABs and 3) the annual variation in larval/juvenile recruitment. Improved capabilities for forecasting year class strength, mortality rate, and larval transport for important fishery resources would also be beneficial. But for the model results to be of most use to managers the output needs to be displayed and accessible in a user-friendly framework to ease understanding and interpretation (i.e. more than just tables of numbers).

Do you see a role for models or model output in your decision-making process?

Models can be used to test the effects of various management scenarios (e.g. increasing the harvest amount of a particular species), forecast some parameter of a system given its current state (e.g. bloom spread), and to gain a better understanding of what controls the dynamics occurring in the ecosystem.. The higher resolutions of the current suite of models allow for greater overlap between the scale of the model and the scale at which managers need to make decisions.

For models to reach their full potential, a number of issues have to be resolved. Models should have the key assumptions clearly identified and there should be some evidence of their reliability. Has the model been tested, does it work? For example, how well do predictions from models fit observed data, has the model been peer reviewed and are the uncertainties well described? Are there any success stories? The models should be able to provide enough insight so that managers can better understand the consequences of their actions especially in an ecosystem context. The models should also be user friendly and easy to manipulate so that they can be run at meetings for quick feedback.

Modelers

Capabilities of modeling system

The inclusion of inshore and estuarine processes is a challenge that will require models to simulate complex physical processes (i.e. turbulence, estuarine transport, bottom shear) at high temporal and spatial resolutions. The biological component of these physical models is still in the rudimentary stages mainly due to a lack of knowledge of life history parameters, interaction terms and behavior patterns. The overall lack of data is a major problem that affects the parameterization and validation of these models. Most models, as a result, have had to resort to simplified representations of the ecosystem under study. Simulations are possible using fully explicit biological dynamics (as opposed to representing the organisms as passive tracers) but care must be taken in interpreting the results especially without a full characterization of the errors introduced with different model formulations and parameter values.

What types of information can be produced by the model?

The suite of models in the Gulf of Maine can produce a wide range of information types. Physical parameters include temperature, salinity, current, density, wave, and tidal distributions. The biological components are often specific to the model but typically involve the prediction of nutrient, phytoplankton (e.g. HABs), and zooplankton (e.g. larval cod) distributions. The trajectory of these organisms can be followed through time as they interact with the physical environment and undergo biological processes such as germination, growth and predation. This information is usually simulated on a daily basis at a spatial resolution of several kilometers. Other model products are available such as; the identification of important physical features (e.g. upwelling zones, convergence zones, low/high flushing areas), conditions favorable for bloom intensification or inhibition, cohort survival and predation rates, population connectedness, the impact of parameter value assumptions and the effects of proposed management actions.

Over the next several years where do you see the biggest/most exciting model improvements?

The acceleration in computer processor power is allowing more detailed models to be constructed. This will allow more processes and state variables to be modeled, a finer grid resolution and a larger simulation domain. Users will also benefit, as many models will become more accessible because high-end computers will no longer be necessary to run the simulations. The increased resolution will enable more physical processes to be resolved (e.g. sharp fronts, turbulence effects) which should allow the models to simulate in greater detail the complex dynamics of inshore systems where many of the management decisions occur. Data availability should increase in frequency and coverage with the addition of instrumented buoys and satellite sensors providing a much-needed boost to model initialization, validation, calibration, and data assimilation efforts. With continued funding for basic research on the biology of important species and on growth and death rate processes, interactions with other species can be better quantified and used to improve model accuracy and predictive power.

What types of data products are needed to initialize or refine your model?

Many of the models have similar data requirements especially with respect to the modeled physical processes. Meterological forcing variables are very important especially for accurate forecasting ability and boundary conditions. Wind, precipitation and temperature are some of the many necessary parameters. Some of this data can be obtained from satellite sensors, radar sources (e.g. CODAR, Doppler radar) and from buoy data (e.g. wind speed and direction, tidal components). There also needs to be data on the distribution of resource variables (e.g. phytoplankton, larvae) and the rates at which those resources change under various environmental conditions and interaction effects with other species (e.g. predator/prey dynamics). Data on these variables is the most lacking and difficult to obtain for many species. In addition, most data for these models needs to be a high temporal and spatial resolutions.

Discussion Recommendations

From the active discussions and information in the focus letter section, a number of issues and needs were raised.

Research Needs

• A better understanding and simulation of near-shore hydrodynamics so that problems of interest to managers can be addressed (e.g. bloom trajectory).
• A greater understanding of the long-term physical drivers so that annual and long-term forecasts can be attempted with greater accuracy.
• To determine the best way to do predictive forecasts for organisms with a patchy distribution or with high temporal variability.

HAB Management Needs

• Real-time to daily forecasts of bloom trajectories disseminated to both state agencies and aquaculture farmers to enable proactive management intervention.
• Long-term forecasting of trends to conduct long-term planning.
• Information that would help in the identification of monitoring locations and aquaculture site selection.
• More information on the loss terms of *Alexandrium* and on the controls of bloom dynamics.

Fishery Management Needs

• Longer term data for closed/open area regulations, what if scenarios, and harvest regulations.
• An understanding of what determines a strong year class and fishery recruitment.
• To quantify cohort production under different environmental conditions.
• To determine where research efforts can make a contribution and provide information to the fishery management councils.

Joint Management Needs

• Real-time information from data sources and short-term model simulations for day-to-day management decisions and for emergency response situations.
• Long-term forecasting of trends to conduct long-term planning and to understand changes due to large-scale drivers.
• Strategic and "what-if" simulations to aid management decisions relating to regulatory decisions.
• Models capable of handling large-scale physical drivers such as the North Atlantic Oscillation, freshwater input, and Gulf Stream rings.

Model Development

• Focus future model development efforts around a core group of models: One model cannot be expected to be applicable to all potential management issues and scenarios. There will be a need for a hierarchy of models for different forecast questions

• Need multiple models for the same question: Using a suite of models will allow a comparison between model results, assumptions, and formulations. When the models agree, there will be more confidence in the result (i.e. forecast) and where they disagree, information can be gained on how the system works. A range of models will have a greater chance of catching deviations in ecosystem dynamics from typical expectations.

• Need an honest assessment of model accuracy, sensitivity, and error: There should be a suite of benchmarks (analytical, hindcasting and forecasting test cases) to compare the skill of the model to the data and to other models.

• Model output needs to be user friendly:

• Need a way to account for uncertainty in model forecasts: Model output should provide some indication of the uncertainty in a forecast.

• Need a model interface standard: To facilitate the use of multiple models and formulations there should be a model interface standard to enable different physical and biological elements to be interchanged.

Model Transition

• Need to define an acceptable level of model inaccuracy: Different questions require different levels of accuracy for the forecasts to be useful for management purposes. These levels of performance need to be defined to give guidance to model development efforts and to identify scenarios that are realistically possible.

• Need to promote continuity in interactions between manager and modeler: Managers need continuity in interactions with modelers in order to realize the full potential of a particular model. Specific questions will require active communication between the two groups and through ongoing dialog, credibility can be established and maintained.

• Need to decide on a list of potential scenarios: There should be some consensus developed as to which cases satisfy the dual constraints of being an important management issue but also addressable with current models.

• Need ecological forecasters to run the models and make predictions: For specific applications, detailed modeling runs by knowledgeable individuals will be needed. Subsequently, the human infrastructure should be developed so that these models can be tested, updated, fine-tuned and run on a regular, sustained basis by people who have intimate knowledge of their performance and limitations.

• Need to decide on a long-term home for the forecast models: Forecast models need a long-term home in order to secure their continuity and funding. Government, state and non-profit organizations are all potential homes since they can help to ensure adequate funding, continuity and expertise. These organizations will also be in the best position and have the capacity to address any potential legal issues from erroneous forecasts.

• Need to build forecasting capacity incrementally: There will be a learning and acceptance period for these projects that has to be built up through a series of success stories which will help to increase confidence, familiarity and trust with the models. Initial efforts should probably focus on giving “guidance” rather than “forecasts” and not promise too much or release a product before it is ready and has long-term funding.

• Need an observational system to support model development: Models used for forecasting purposes generally have extensive data needs (e.g. calibration, verification, benchmarking, assimilation).

• Need a cost-benefit analysis of proposed forecasts: The limited resources of government and state agencies necessitate determining the value (e.g. economic, societal, ecosystem) gained from providing a particular forecast or maintaining a forecasting capability.

• Basic research needs continued funding support: Forecasting systems will always have a need for a greater understanding of the driving processes, life history dynamics and multispecies interactions and research funds to support these efforts should be continued.

Need to decide on the type of forecast to be attempted. The type of forecast to be attempted (i.e. guidance vs. forecast) will fundamentally affect many other aspects of the model transition process. Providing an operational project is not a simple endeavor and requires a serious commitment of time, personnel and resources. Model forecasts, especially operationally based, should probably not be attempted without extensive experience with giving guidance forecasts.

Future Workshops
Expose managers to the full range of possible model products. A follow up workshop focusing only on the models, in an interactive framework, could be very beneficial to the model transition process. This workshop would expand upon the first one by allowing the managers to get a “hands on” feel … Details about each of the models would be presented such as the data needs, assumptions, model accuracy and model capabilities followed by an interactive session where managers and modelers could go through various simulation experiments together. Managers would gain familiarity and an understanding of what would be involved for various model products thus gaining a greater awareness of what would be realistically possible. With this perspective, managers can then give more appropriate and focused suggestions for possible model tools, enabling future efforts to focus on these areas with greater success.

Identify specific problems to address: define a “restricted” set of “realistic” model products that would be of interest to “both” communities. Once these products are identified, the data, research, and infrastructure needs to implement the project can be discussed and acted upon. Ideal candidate projects would be those that could be started with little development, using existing capability and provide simple forecasts that could then be built upon sequentially.

Identify where additional observations are needed. Models have extensive data needs that must be addressed before management oriented forecasts can be attempted. These needs include model initialization, boundary conditions, providing realistic model parameter values, data assimilation and judging the hindcasting/ forecasting skill of simulation results. The workshop can identify these data needs and develop the appropriate sampling and monitoring network necessary to drive the various management models. Over what time frames and space scales is information needed?

Specify the criteria on which to judge model accuracy. A framework needs to be developed to test the accuracy of a potential model with respect to a “benchmark model and/or dataset” and to the level of skill necessary for the particular model application. Different applications will require different levels of accuracy so identification of these levels and the appropriate tests is vital to further progress.

Determine the most useful types of forecasting systems. The type of system employed will usually depend on the model and desired product. Forecast systems can range from a totally automated system, where the manager just has access to the model output to one where the manager is responsible for setting up, running, and interpreting the simulations. Each of these systems will involve various levels of input and cooperation with model developers that must also be addressed.

Discuss long-term model transition issues. Transitioning research models to management applications involves many complex issues. Assuming that a model product survives the difficult development, testing, and acceptance period there are still many hurdles. Who will run the model, both for idealized and novel scenarios (scientist, manager, collaboration, ocean forecaster)? Where will the model be housed (federal government, state, regional observing system, partnership)? Who will fund the model (development, day-to-day operations, improvements)? Who will assume the legal responsibility (human illness, lost revenue, overharvested stocks)?

Summary
Transitioning research models, such as those developed through the ECOHAB and GLOBEC programs, to the management community is a difficult and complex task. This is a challenge because research models are rarely

directly applicable (e.g. different focus) or accessible (e.g. too complex) to the management community. Successful transition will require an active dialog, between the research and management community to ensure that developed model products are applicable to management and societal concerns.

All of the models presented at the workshop hold promise as a potential tool to aid resource managers. They have well-developed physical components capable of representing the general circulation and transport processes present in the Gulf of Maine. Physical transport simulations can be used to provide short-term forecasts of passively dispersed particles (e.g. oil, larvae, phytoplankton) over short time frames. The use of data assimilation techniques may help to extend these forecasts. Models have typically suffered from resolution issues and a lack of data but increases in computer speed and more extensive monitoring networks promise to increase the resolution of the current models. The simulations of inshore dynamics or frontal boundaries are now possible but there is still much work to be done to fully characterize the accuracy of these models within such a dynamic environment. These conditions create enormous data needs (e.g. model initialization, calibration and verification) which still need to be addressed if the models are to reach a stage where they can provide timely forecasts.

The long-term goal of this model transition effort is to create operational model products capable of providing ecological forecasting for the safeguarding of local economies and public health. Unfortunately, ecological based forecasting has a long way to go before reaching the funding, experience, infrastructure, and familiarity of other operational based products such as weather forecasts. Ecological forecasting also has the added hurdle of needing to incorporate complex biological dynamics on top of the already complex physical dynamics. The forecast applications that will hold the greatest promise are those that are combined with other tools used by resource managers. These model products will never replace traditional tools (e.g. mouse bioassays, fishery surveys) used by managers but can provide additional vital information to complement the other data sources that are part of a larger process that has forecasting as just one of the components.

January 2001

Scientific Workshop on the Gulf of Maine Ocean Observing System, Inc. (RARGOM Report 02-1)

Coordinate modeling activities within the GoMOOS project with other modeling groups working in the region, as wells as the modeling community in general.

Interaction between the open ocean and the coastal circulation is a topic at the forefront of physical oceanographic research and GoMOOS modeling stands to make an important contribution.

The scientists involved in Gulf of Maine modeling activities will benefit greatly from coordinating with each other in a collegial and collaborative environment. Such an atmosphere will foster intercomparison of models with GoMOOS data, as well as other data sets.

The GoMOOS policy of open access to data can serve as a cornerstone strategy. Common formats, standards, time conventions, etc. are very important. Ideally the system will conform to and help to guide national/international protocols.

Use models to provide quantitative feedback into future design of the GoMOOS observational network through Observational System Simulation Experiments.

Help define a vision for linked observational/modeling systems as well as how they are networked regionally/nationally/internationally.

Coupled physical/biological/optical modeling can connect broad-scale surveys with small-scale measurements over many trophic levels.

GoMOOS needs to work with the scientific community and with the coastal interests (scientists, managers, citizen and environmental groups and others) to clearly define how the broader scale GoMOOS measurements can interact with and benefit the numerous nearshore issues.

April 2000

Establishing a Framework for Effective Monitoring of the Gulf of Maine (RARGOM Report 00-1)

Many management issues are amenable to modeling. Examples include: redtides/shellfish closure, bacterial contamination/shellfish & beach closures, nutrient loading/eutrophication, aquaculture net-pen siting, oil and gas drilling, emergency response, shipping, navigation, and general transportation.

Many models are available for the Gulf; much observational data are being collected within many long-term programs. However, there are **no sustained measurements of key parameters nor is there any coordinated regional scale integration or interpretation of data**.

Challenges to the use of models include: comparing different models created for the same purpose, integrating physical and biological models, and coupling the benthos with models for overlying water.

Creation of a regional monitoring council championed by a federal agency, probably NOAA is needed. This council could oversee the creation of a regional modeling center to perform the following functions:

1. **facilitate integrated planning**
2. **arrange information dissemination via a distributed information system**
3. **solicit long-term maintenance commitments from participants**
4. **encourage managers to use this capability**
5. **host regular meetings with management setting the agendas and with scientists involved and responsive**

June 1997

Mechanisms for Improving the Integration of Science and Management in Decisions Affecting the Environmental Quality of the Gulf of Maine (RARGOM Report 97-2)

Establish independent and credible scientific advisory groups to help identify emerging issues, to set priorities for research and to provide the best available advice on issue of immediate concern.

Provide financial resources to enable scientists to participate in applied scholarship, technical advisory roles, and the identification of research needs that are important to resource managers.

Public agencies and research organizations should support scientists and managers who serve a synthesizers, translators, and communicators in the integration of science into management decisions and public policy.

Regional organizations should establish, maintain and enhance the information infrastructure.

Develop better procedures for risk assessment and estimates of uncertainty.

Use adaptive management techniques, including research and monitoring programs, to evaluate the impacts of policy decisions, to test predictions of environmental impacts, and to provide timely communication of results to project management.

September 1996

Proceedings of the Gulf of Maine Ecosystem Dynamics (RARGOM Report 97-1)

Ecosystem modeling was one of the unifying themes of the Symposium, both as a framework fro conducting research and as a means of communicating results. (p5) There has been tremendous growth in the development and use of circulations models in the Gulf of Maine, although coupling of biological and chemical processes into these models is at an early stage.

Elements limiting the successful development of models are inadequate resolution of the temporal and spatial domain of the both the appropriate physical and especially biological processes, the failure to design physical circulation models that can be easily coupled with biological models, and the lack of adequately resolved biological models that include the necessary conceptual framework and rates of key dynamical processes.

Development of a predictive ecosystem model for the Gulf of Maine must begin with establishment of a yet to be realized over-arching conceptual model of the system followed by identification and acquisition of the necessary data on biological processes and rates.

Successful integration of such data into physical circulation models require that the physical models be developed in a truly interdisciplinary sense that recognizes the structural, temporal and spatial scale requirements of the biological processes being incorporated into the model.

The proliferation of models raises important questions regarding the ability to sustain and nurture the continued evolution of modeling in the region that retains the best elements of the existing models, avoids duplication of effort, and promotes integration of other system sub-models. …**establishment of an institutional commitment to long-term model development in the region [is needed] to achieve these goals**. An example of the need for such a commitment is the current inability to maintain and support the water quality model developed for the MWRA, despite widespread recognition of its past and potential future contributions to both scientific and management interest in the Massachusetts and Cape Cod Bay area. Such an institutional commitment is also consistent with the need to link long-term monitoring efforts to modeling activities for the mutual benefit of both.

September 1995

The Health of the Gulf of Maine Ecosystem: Cumulative Impacts of Multiple Stressors (RARGOM Report 96-1)

(pgs. 3-4)

Identify critical linkages between ecosystem components and subsystems and their sensitivity to cumulative and individual stressors. Significant advances have been made in understanding subsystems, but the ecosystem dynamics of the Gulf of Maine as a whole are poorly understood. A combination of field and modeling studies must be conducted at logistically feasible and manageable levels of effort.

Use interdisciplinary research approaches, working to link cumulative and individual stressors of the system to their effects (reflecting the strong gradient of anthropogenic stressors in the Gulf of Maine).

Evaluate resilience (recovery from disturbance) of ecosystems and ecosystem components known to be affected by natural and anthropogenic stressors (response to multiple stressors) and establish predictable recovery(ies).

Develop criteria to assess sensitivity of coastal embayments and estuaries from an interdisciplinary perspective of habitat change; contaminant introduction, fisheries harvesting, and physical and biological process. Because embayments and estuaries are both directly or indirectly affected by anthropogenic activities in adjacent watersheds, linkages between any two such systems also need to be established.

April 1994

Gulf of Maine Habitat (RARGOM Report 94-2)

p.112

Research required to provide knowledge for a habitat based approach to managing for biodiversity includes:

1. Determining the appropriate scale for resolving features of habitat and communities suitable for management for each habitat type. (Selection of representative habitats is required for this research component). This work requires determining the appropriate physical parameters needed for characterization of each habitat type.
2. Determining the role that biodiversity lays in maintaining ecosystem health vis a vis the functional role of biodiversity n carbon flow, contaminant cycling and sequestering of carbon/contaminants.

p.114

Coastal Habitat Management Needs

1. Ecological parameters and processes:

define and measure functions and values of existing habitats
determine processes necessary for long-term habitat stability
determine linkages between coastal zone and offshore processes

p.116

Develop hydrologic models to guide restoration of tidal flow
Develop ecological models to predict the rate and extent of changes in functions and values with loss/restoration of tidal flow
Develop a model describing the relationship between macroalgal habitat, urchin propulation structure and lobster population structure

p.118

Develop models to predict response of target Gulf of Maine resources (coastal and offshore) to coastal habitat alteration
p.124
Development of numerical models that quantitatively describe know habitats/species interactions and explore potential areas of habitat research
p.137
The link between potentially toxic contaminant concentrations and biotic effects must be better established.
Transport paths must be studied to determine how contaminants move and become mobilized in the environment and subsequently become accessible to organisms.
The effectiveness and net costs of remediation practices in meeting goals needs to be more clearly established.

1993

Gulf of Maine Circulation Modeling (RARGOM Reportn94-1)
The need for valid circulation models of the Gulf of Maine is repeatedly expressed by both the scientific and resource management communities. On the scientific side, the ability to simulate circulation is a fundamental prerequisite to construction of nutrient, water quality, and ecosystem models. Further, the availability of scientifically sound models of the Gulf which could be operated within management units is a real possibility n the near term and promises to contribute enormously to wise stewardship of Gulf resources.

The range of modeling approaches in use in the Gulf of Maine today is very broad and covers all of the primary branches of computational science. Despite this diversity, it was generally agreed that all modeling efforts are converging on the same underlying physics: the classical nonlinear description of a 3-D hydrostatic, baroclinic, boussinesq fluid, with prognostic treatment of the temperature and salt fields, resolved on realistic topography in tidal time.

The various modeling results achieved to date are full of promise. In addition, we are on the threshold of a quantum leap in the observation support for circulation models – currents, drifter trajectories, hydrography, sea surface temperature— made available by the union of the Regional Marine Research, Sea Grant, and GLOBEC programs in the Gulf region.

It is therefore appropriate to contemplate the formation of a Gulf of Maine Modeling Center. Such a center would amplify individual modeling projects, make model results more accessible to the broader scientific community, and facilitate the evolution of more complex models which go beyond circulation per se.

Specific technical activities of a center would include:
Provide a point of access to archived model flow fields
Facilitate the transfer of models themselves from research institutions to operational agencies
Provide easy access to model input data: topography, climatology, winds, river flow, etc.
Maintain and develop visualization tools at various levels of sophistication
Define and service standards for large data files and their interface to diverse programs and packages
Development of interfaces to advanced 3-D visualization packages
Develop interfaces among models, in particular among circulation models and water quality and ecosystem models
Provide community access to poled equipment (disk farm, advance video hardware; etc.) as needed

Establishment of such a modeling center would be a major step toward broader utilization of circulation models and their evolution toward more complex models of the Gulf ecosystem. A basic challenge to all Gulf of Maine constituencies is to seek an appropriate institutional setting for such a center, and to begin its nurture toward a truly cooperative service organization connecting modelers, scientists, and the public interest.

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Appendix B: Workshop Agenda

RARGOM Modeling and the Observing System Workshop Agenda

Wednesday, July 6, 2005

The management-research connection in relation to the observing system: meeting user needs and critical modeling issues.

08:30 Arrival and Registration, Name Tag Pickup, Coffee

09:00 **Welcome, Introductions, Meeting Format and Objectives (Jeff Runge, UNH)**

09:20 **The Relevance of Modeling to Coastal Management in the Context of an Ocean Observing System for the Gulf of Maine (Josie Quintrell, GoMOOS)**

9:50 **Gulf of Maine Circulation Modeling: Prospects for Skill and Critical Issues (Dan Lynch, Dartmouth)**

10:30 Break

11:00 **Incorporating Fisheries Oceanography into Ecosystem Based Management for Fisheries (Ken Drinkwater, Institute for Marine Research, Norway)**

11:40 **Coastal Management Issues: Water Quality (Bob Chen, UMass Boston)**

12:15 Lunch followed by **Poster Session**

14:00 **Working Groups Identified and the Charge to Working Groups Discussed (Jeff Runge, UNH)**

14:15 **Working Group Meetings:** Habitat, Fisheries, Water Quality

16:15 **Summaries of Working Group Discussions**

17:15 **Poster Session** continued

18:30 Dinner

20:00 **Coupled Physical Biological Models and the Observing System: the Rhomboid Approach (Peter Wiebe, WHOI, with Doug Spiers, Univ. Strathclyde, UK, and Marina Chifflet, DFO Canada)**

Thursday, July 7, 2005

Critical modeling issues and model-data needs: priorities for development of interdisciplinary model capabilities and identification of data gaps in relation to observing system needs

09:00 **Ocean Observing and Operational Oceanography in Canadian Waters (David Brickman, DFO Canada)**

09:30 **Coupling Basin Scale to Gulf of Maine Models (Bob Beardsley, WHOI)**

10:00 **Present Status of Observing System Sample Collection and Data Acquisition (David Mountain, NEFSC)**

10:30 **Working Group Meetings:** Data Needs and Critical Issues for Models in the Context of Observing System: Physical Circulation Modeling, Coupled Physical-Biogeochemical Modeling, Coupled Physical-Zooplankton, Larval Fish and Ecosystem Based Models

12:30 Lunch

13:30 **Working Group Meetings:** Visions for a Regional Modeling Center: Rationale, technical activities/services, data and model performance, administrative structure, outlining a process for establishment, strategies to achieve this goal

16:00 **Plenary Session for Working Group Reports and Discussion**

17:30 **Meeting Wrap-up, Next Steps, Adjournment**

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Appendix D: Poster Abstracts

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Ata Bilgili
Thayer School of Engineering
Dartmouth College

A Lagrangian particle method embedded within a 2-D finite element code, is used to study the transport and ocean-estuary exchange processes in the well-mixed Great Bay estuarine system in New Hampshire, USA. The 2-D finite element model, driven by residual, semi-diurnal and diurnal tidal constituents, includes the effects of wetting and drying of estuarine mud flats through the use of a porous medium transport module. The particle method includes tidal advection, plus a random walk model in the horizontal that simulates sub-grid scale turbulent transport processes. Our approach involves instantaneous, massive [O(500,000)] particle releases that enable the quantification of ocean-estuary and inter-bay exchanges in a Markovian framework. The effects of the release time, spring-neap cycle, riverine discharge and diffusion strength on the intra-estuary and estuary-ocean exchange are also investigated.

The results show a rather dynamic interaction between the ocean and the estuary with a fraction of the exiting particles being caught up in the Maine Coastal Current and swept away. Three somewhat different estimates of estuarine residence time are calculated to provide complementary views of estuary flushing. Maps of residence time versus release location uncover a strong spatial dependency of residence time within the estuary that has very important ramifications for local water quality. Simulations with and without the turbulent random walk show that the combined effect of advective shear and turbulent diffusion is very effective at spreading particles throughout the estuary relatively quickly, even at low (1 m2/sec) diffusivity. The results presented here show that a first-order Markov Chain approach has applicability and a high potential for improving our understanding of the mixing processes in estuaries.

A Physical-Biogeochemical Model of the Gulf of Maine: Near-Real Time Simulation of Ecosystem Dynamics

Fei Chai, Huijie Xue, Guimei Liu, Andrew Thomas, and Ryan Weatherbee
School of Marine Sciences
University of Maine

With recent advancing in ocean observations and improving in coastal circulation modeling, ecosystem dynamics and its response to change of physical conditions can be investigated by conducting near-real time physical-biological model simulations. A multiple nutrient and plankton ecosystem model has been implemented into a circulation nowcast/forecast system for the Gulf of Maine, which is an integral component of the Gulf of Maine Ocean Observing System (GoMOOS, gomoos.org). The nowcast/forecast system, which is based upon the Princeton Ocean Model (POM), has produced daily short-term forecasts of the circulation and hydrographic properties in the Gulf of Maine. The physical-biogeochemical model has been used to reproduce daily nutrients and chlorophyll fields for the period of January 2002 to June 2005. The model performance is evaluated with both the SeaWiFS and GoMOOS in situ chlorophyll observations at several key locations in the Gulf. The spring phytoplankton blooms for the past four years (2002 to 2005) have shown strong interannual variability from the SeaWiFS derived chlorophyll concentration, but the model tends to produce weaker year-to-year spring bloom. The potential factors that might cause such difference will be discussed.

Chen and Beardsley Poster Abstract <to be submitted>

Chifflet Poster Abstract <to be submitted>

Cabell Davis Poster Abstract <to be submitted>

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Mingshun Jiang
University of Massachusetts at Boston

Based on modeled and observational results, a significant correlation is found between the coastal transport in Massachusetts Bay (MB), *Calanus finmarchicus* abundances in Cape Cod Bay (CCB) and North Atlantic right whale sightings in CCB during spring (1997-2003). Zooplankton is normally transported from MB into CCB every spring, providing the key external population source to right whale. Disruption of this operational mode such as in March 2002 would have dramatic consequences to the *C. finmarchicus* abundances and hence the right whale foraging in CCB.

Jim Manning 2 Poster Abstracts <to be submitted>

Appendix E: Red Tide Session

During the evening of July 5th, several workshop participants met to discuss the extensive outbreak of *Alexandrium fundyense* in the Gulf of Maine during the late spring. The scope of the harmful algal bloom closed shellfish beds from Maine to the southern shores of Massachusetts, exceeding prior range and concentration levels of any prior year. The topic was well suited for exploration in the context of this meeting, as it exemplified the need for modeling activity to elucidate research results and serve as a resource management decision-making tool.

Several members from a red tide research team presented results from a cruise conducted from May 9-18th on the research vessel Oceanus that surveyed water sectors from Massachusetts Bay to the Bay of Fundy. Their goal was to sample, analyze and model how physical, chemical and biological factors combine to distribute and disperse *Alexandrium* algae throughout New England waters. It was during this time that initial evidence of a major bloom emerged.

The Quoddy model was used on shipboard, generating real-time simulations that illustrated the conditions that set the stage for red tide; animations of particulate movement based on this model were shown to the group. The results enabled resource managers to understand where the *Alexandrium* bloom might develop over a three-day timeframe and plan their response.

Data-collecting drifters released in the region of a major source of *Alexndrium*, were tracked by satellite to establish the influence of currents on the destinations of *Alexandrium* floating in the water. This information was used to confirm the accuracy of simulated circulation patterns.

Alexandrium is considered to be harmful at levels of 1000 cells/liter of water. In May, a water sample collected on the research vessel Oceanus contained 2,000 cells/liter. Two weeks later, a rapid response survey cruise of the Massachusetts coast, found concentration levels of 42,000 cells/liter– levels never seen before.

The group explored the factors that may have contributed to these 2005 events:

(1) Heavy winter snowfall and high spring rainfall, coupled with a significant northeaster event on May 7th, contributed high levels of fresh water runoff, which was then forced into coastal waters by the storm winds, carrying high density levels of *Alexandrium* shoreward in the process.
(2) High levels of *Alexandrium* cysts were detected in seafloor samples collected from the fall 2004 survey, indicating that there had been a large 2004 bloom, which set the stage for a new bloom in the following year cycle. A survey is planned for the fall 2005 to further explore this theory.
(3) Cysts already present in the water column
(4) Nutrient abundance
(5) Warm temperatures in western Gulf of Maine waters

Participants included Ata Bilgili, Genie Braasch, Fei Chai, Cabell Davis, Kevin Friedland, Ruoying He, Randy Losier, Dan Lynch, Jim Manning, Linda Mercer, Ru Morrison, Jeff Runge, Beth Turner, Peter Weibe, Huijie Xue

Schematic of Regional NE Model System

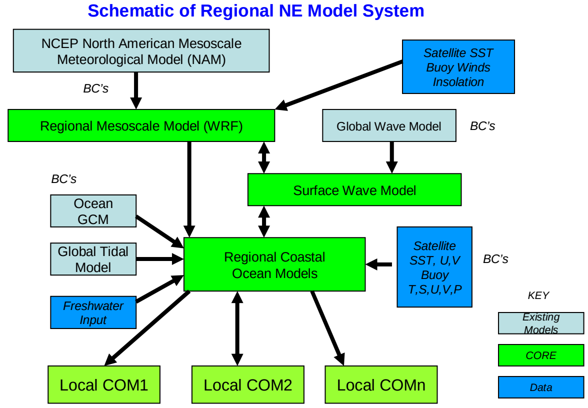

Figure 3.1. Schematic diagram of linkage among atmospheric and ocean models and data at various scales for application to the Gulf of Maine (courtesy of R. Beardsley, WHOI)

The Gulf of Maine Environmental Testbed Forecast Center

-**To develop, generate, test, and verify experimental environmental analysis & forecast products for users in the Gulf of Maine for possible operational implementation in NOAA, in collaboration with NOAA's operational (regional and national forecast centers*) and research centers (e.g. NMFS labs, NOAA-UNH centers, NH's SC, NCEP/EMC, NOS/CSDL&NCCOS&HAZMAT, NESDIS), state agencies, regional observing systems, universities, & private sector.**
- **Operate 5 days x 8 hours with deadlines for issuing products**
- **Interaction between marine meteorologists, oceanographers, hydrologists, climatologists, etc…**

Real-Time Data Ingest

Meteo, River, Oceanographic, Water Quality, Air Quality, Biological Info

- In-Situ Observations
- Remotely Sensed Data
- NWS and NOS Forecast Model Guidance
- NOAA/NOS Bathymetry

Education & Outreach

- On-Job training for '*ocean forecasters*'
- Outreach to users in cooperation with NOAA outreach personnel (NWS WFO WCMs, NOS NE-NM, SeaGrant extension) to educate uses on exp. products and get their feedback

Environmental Model Test Bed Computer Facility

- To develop and test forecast models in semi-operational mode and perform skill assessment based on NOAA standards
- NWP (WRF) Model
- Oceanographic Models (Gulf & Estuaries)
- Water Quality
- Air Quality

Experimental Analysis and Forecast Products

- Forecast horizon: 0 hrs (analyses) to seasonal forecasts
- Focus on 2-3 applications (e.g. water quality, fisheries, HAB) at any one once
- Use demonstration periods to obtain detailed feedback
  - Forecast Discussions (interpretations)
  - Digital (gridded) Data
  - Graphical & Visualizations

* National: *NWS/NCEP/OPC & NOS/CO-OPS,* *New England: NWS/NE River Forecast Center, NWS Weather Forecast Offices*