# Modeling Ecosystems and Ocean Processes Workshop

*by Enrique Curchitser, Alejandro Gallego, Michio Kishi and Emanuele Di Lorenzo*

A 2-day workshop on "*Modeling Ecosystems and Ocean Processes: The GLOBEC Perspective of the Past, Present, and Future*", co-convened by the authors of this article, was held at the 2009 GLOBEC Open Science Meeting (June 22–23). It attracted a considerable interest, with approximately 50 attendees over both days. The general goals of the workshop were to summarize the physical and biological modeling activities during the GLOBEC years and discuss future directions. The workshop was divided into four sub-topics: (1) Physical and biological modeling, (2) Biological and advanced ecosystem models, (3) Frontiers in ecosystem modeling, and (4) Climate change in regional marine ecosystems, although there was some unavoidable overlap between these. Workshop activities included five invited (review) talks (by Francisco Werner, Raghu Murtugudde, Jerome Fiechter, Michael Follows and Kenneth Drinkwater), which introduced individual sub-topics, and over 35 submitted talks, in addition to six posters and a final discussion session. Some of the common themes that emerged from the discussions and some of the presentations focused on (1) end-to-end models, (2) agent-based models, (3) complex food-webs, (4) simple *vs*. complex ecosystem models, and (5) evolutionary models.

The traditional ("classical" or more "advanced") physical–biological coupled models, especially NPZD models coupled with three-dimensional physical models, have achieved considerable progress in the study of marine ecosystems. For long-term predictions, like the ecosystem response to climate change, traditional methods using physical–biological coupled models are still useful. Since the 1990's, IBM (Individual Based Models) have been successfully employed to capture much of the physical-biological interaction in marine ecosystems. The IBM approach has also been widely used in modeling zooplankton or larval fish behavior. However, as it was pointed out during the discussions, the more complex models need more data to assess the degree of realism and more parameters need to be specified. There is ample space for discussion on this matter, but we must recognize that, although advances in computing technology allow us to increase the number of biological compartments or refine the grid in our models, ecosystem models are just "models", *i.e.*, representations of nature. Nevertheless, as the impacts of climate change become manifest in all components of the Earth System, the need for high resolution (meter scale) multi-compartment modeling frameworks for policy and decision-making and adaptive management is very clear. The IPCC-class models continue to enhance their spatial resolutions but participatory decision-making on the ground will always require further improvements in the resolution at which Earth System information is provided with its irreducible uncertainties, and will require dynamic and statistical downscaling.

A prototype implementation of a regional Earth System prediction framework was illustrated for Chesapeake Bay by Ragu Murtugudde (Fig. 1). This forecasting system uses the WRF (Weather Research and Forecasting) regional atmosphere model, NOAH land model, ROMS (Regional Ocean Modeling System) ocean model and the SWAT (Soil and Water Assessment Tool) watershed model to generate seasonal predictions and decadal projections for not only meteorological and climatic variables but also for nutrient and sediment loading of streams, pathogens, harmful algal blooms, fisheries, dissolved oxygen, and other ecosystem parameters. An important aspect of this type of regional Earth System prediction approach is to recruit users such as city water supply managers, parks and river keepers, and watermen so that the model forecasts are employed in decision-making. This allows quantitative feedbacks from the users that are important to validate, optimize, provide uncertainties, and improve skills and products of the Earth System prediction. In the case of the Chesapeake Bay system, an interactive decision-making tool has been developed such that users can change land use types, crops, urban sprawl, emissions, population, and other variables of interest to track the impacts on air and water quality, health of the coast–estuarine ecosystems, pathogen levels, and other critical system indicators. While the task of validating the output of these systems with data remains an important issue to address, the philosophy is to demonstrate the feasibility of regional Earth System prediction and its usefulness in determining the observational data needs.

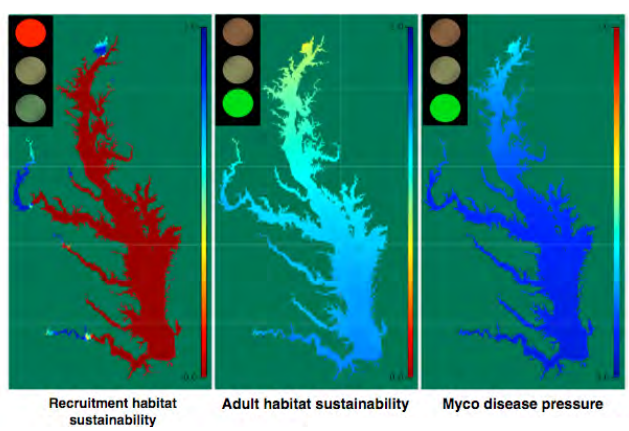


*Fig. 1 Example of the Chesapeake Bay Earth System Prediction framework. Panels show an example of various stress parameters for Striped Bass during a simulation of severe drought in July 1999 (courtesy of R. Murtugudde, University of Maryland, U.S.A.).*

Other topics of discussion about future progress and model applications included the use of modeling tools to describe species migrations (in regional models), including the spread of "invasive" species or, in terms of methodology, allowing for shifting parameters/distributions to describe entropy maximization. An interesting approach based on the self-organizing principle of marine ecosystems was presented by Michael Follows, where the marine ecosystems are organized by the relative fitness of the myriad of potentially viable phenotypes in a given environment. With this guiding principle an ocean model is seeded with many tens or hundreds of plausible phytoplankton physiologies, which are then allowed to "self-organize". Using this approach, a familiar pattern of biogeographical provinces naturally emerge in the model, with a subset of the initialized organisms ultimately dominating the population of each province. The emergent biogeography is broadly plausible, with pleasing correspondence between observed and model–analog ecotypes of the cyanobacterium *Prochlorococcus* (Fig. 2). These types of complex model solutions can be understood using established ecological concepts; in particular, it was found that resource competition theory accurately anticipates the characteristics of the modeled subtropical ecosystems. Based on these results, it was suggested that such "self-assembling" ecosystem approaches are particularly suitable for modeling the broader food web and will provide preliminary illustrations incorporating heterotrophic microbes and predators in a similar manner.

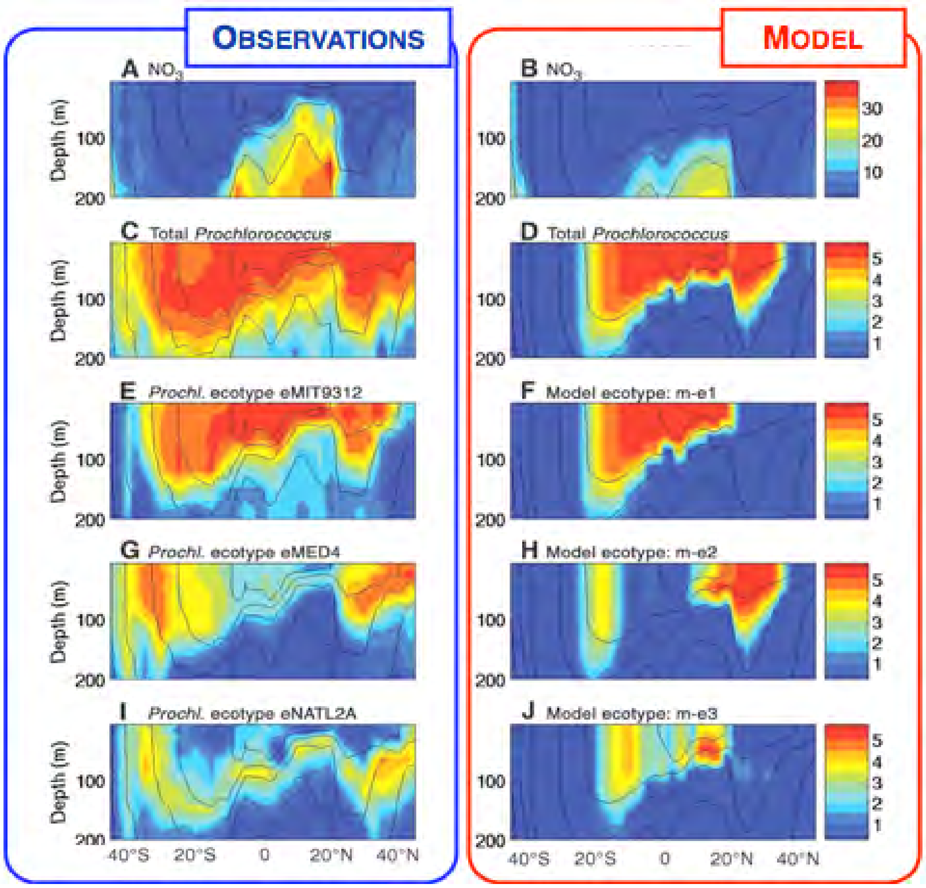


*Fig. 2 Observed and modeled properties along the AMT13 cruise track. Left column shows observations, right column shows results from a single model integration. (A and B) Nitrate (µmol kg$^{-1}$); (C and D) total* Prochlorococcus *abundance [log (cells ml$^{-1}$)]; (E, G, I) distributions of the three most abundant* Prochlorococcus *ecotypes [log (cells ml$^{-1}$)] ranked vertically; (F, H, and J) the three emergent model ecotypes ranked vertically by abundance. Model* Prochlorococcus *biomass was converted to cell density assuming a quota of 1 fg P cell$^{-1}$. Black lines indicate isotherms. Source: Follows* et al.*, Science 315, 1843–1846 (2007).*

Another interesting avenue for future ecosystem modeling was discussed by Jerome Fiechter. The approach involves combining existing ecosystem models with Bayesian Hierarchical Models (BHM). BHM is a unified probabilistic modeling methodology that updates uncertain distributional knowledge about process models and parameters in the presence of multi-platform observations. Summary measures of the resulting "posterior" distributions provide realistic quantitative estimates of central tendencies and uncertainties. Process model distributions are based on NPZD-type lower trophic level ecosystem models, including NEMURO (North Pacific Ecosystem Model for Understanding Regional Oceanography) specifically developed and parameterized for the North Pacific Ocean. A significant outcome of BHMs will be a quantitative understanding and comparisons of the relative uncertainties of modeled state variables and parameters (*e.g.*, from NPZD or NEMURO), region-by-region across different oceanic ecosystems.

As a general observation, the ROMS emerged as the most widely used physical model for coastal and shelf applications, although results using other physical models were also presented. In the case of NPZD models, there was a wide degree of "regional variability". The size of NPZD models averages around ten compartments. In most of these models, each phytoplankton and zooplankton is divided into two to four compartments. The NEMURO model, which was developed by the PICES CCCC (Climate Change and Carrying Capacity) Program's MODEL Task Team, was one of the more popular NPZD models. One of the topics that came out in the discussion period was that the number of compartments in a biological model is not necessarily a measure of its complexity. A four-compartment model may have more parameters to tune, thus making it more complex than a ten-compartment model which has simple feedbacks. The question of what is the appropriate level of complexity was widely discussed and, in the mind of the organizers, will continue to be an important topic in the near future. The workshop was a fitting final presentation of GLOBEC modeling work. We thank the OSM organizers and all workshop attendees and participants and, in particular, we appreciate the interaction with so many GLOBEC friends through these last ten years. The organizers would also like to thank Ivonne Ortiz and Jerome Fiechter for helping with running the workshop.

*Left photo (left to right): Enrique Curchitser, Jerome Fiechter (who helped to run the workshop in the absence of Emanuele Di Lorenzo), Alejandro Gallego and Michio Kishi after completion of the workshop. Right photo: Emanuele Di Lorenzo (left) and Enrique Curchitser (right) in a rare moment of not thinking about low-frequency variability and regional climate impacts.*

*Dr. Enrique Curchitser (enrique@marine.rutgers.edu) is a physical oceanographer based at Rutgers University in New Jersey, U.S.A. In spite of living near the Atlantic, most of his work is on the Pacific Ocean. His main interests are the intersection of climate and biology, regional climate impacts and numerical modeling. His current projects range from downscaling climate scenarios in the northeast Pacific and Bering Sea to trying to understand the low-frequency fluctuations in global sardine populations. He is a member of PICES Working Group on Evaluation of Climate Change Projections.*

*Dr. Alejandro Gallego (a.gallego@marlab.ac.uk) is Leader of the Bio-Physical Processes Group, in the Aquatic Environment Programme of the Marine Laboratory Aberdeen, which is part of Marine Scotland, a Directorate of the Scottish Government. He has carried out experimental work on larval fish ecology, but his main field of research for a number of years has been biological and bio-physical modeling of zooplankton and early-life stages of fish. Alejandro is a member of a number of ICES Working Groups, such as WG on Recruitment Processes (WGRP) and WG on Modelling Physical-Biological Interactions (WGPBI), where he is an enthusiastic participant in its informal "larval fish sub-group", and has been the co-convenor of a number of workshops organized under the auspices of this Group.*

*Dr. Michio J. Kishi (kishi@salmon.fish.hokudai.ac.jp) is Professor at the Faculty of Fisheries Sciences, Hokkaido University, Hakodate, Japan. He is also a Team Leader at the Research Institute of Global Change, Japan Agency for Marine-Earth Science and Technology (JAMSTEC). His research interests include top-down control of regional ecosystems by migrating fish and marine mammals, ecosystem-based management of marine resources, development of NEMURO-family models and their application to fish ecology. For his modeling work Dr. Kishi received the 2005 Uda Prize from the Japanese Society of Fisheries Oceanography and the 2007 JOS Prize from the Oceanographic Society of Japan. In PICES, he was a member and Co-Chairman of the MODEL Task Team and has been serving as Co-Chairman of the Climate Change and Carrying Capacity (CCCC) Program since 2006.*

*Dr. Emanuele (Manu) Di Lorenzo (edl@gatech.edu) is Associate Professor at the School of Earth and Atmospheric Sciences, Georgia Institute of Technology, U.S.A. His research interests and experience span a wide range of topics from physical oceanography to ocean climate and marine ecosystems. More specific focus is on dynamics of coastal ocean circulation, regional ocean predictability and inverse dynamics, Pacific low-frequency variability from coastal to global scales, and impacts of large-scale climate forcing on regional ecosystem dynamics. His work relies on combining advanced numerical, statistical and inverse models of the ocean circulation (and ecosystems) with observations. Manu is also involved in using IPCC class coupled climate models to better understand the links between large-scale dynamics, climate change and ecosystem response. In PICES, he is a member of the Working Group on Evaluations of Climate Change Projections.*