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A Software Framework for Integrating Marine Ecosystem Models

FY 2005 Proposal to the NOAA HPCC Program

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Proposal Theme: **Technologies for Collaboration, Visualization, or Analysis**

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A Software Framework for Integrating Marine Ecosystem Models

Proposal for FY 2005 HPCC Funding

Prepared by: Thomas C. Wainwright

Executive Summary:

The North Pacific Marine Science Organization (PICES) coordinates governmental ocean research programs across the North Pacific basin. It's Climate Change and Carrying Capacity (CCCC) program tracks the effects of climate change on production of marine resources in the basin. In support of this program, the MODEL Task Team (http://www.pices.int/members/task_teams/MODEL.aspx, http://161.55.120.140/foci/model/index.html) has developed a suite of models for plankton and fish bioenergetics (the "NEMURO" models) which have been applied to local areas around the North Pacific. The Team's work is entering a synthesis phase, during which we plan to develop more local-to-regional scale applications, and link those with basin-scale forcing models, with an eventual goal of looking at basin-wide ecosystem response to climate forcing. While the NEMURO models are already being used for analysis, their current implementation limits use in collaborative synthesis-phase projects; in particular, the code and interface is not easily adapted to new applications. The emerging Earth System Modeling Framework (ESMF, http://www.esmf.ucar.edu) is designed to facilitate linkage of systems models and components by providing a common modeling infrastructure, and thus may be an ideal tool for improving PICES collaborative model development and expand the geographic extent of its application. We propose an international collaboration to improve the NEMURO model suite by integrating it within the ESMF. Main accomplishments will be: (1) recode NEMURO models within ESMF, (2) develop API documentation and users guide for NEMURO models, (3) implement a web-based interface for displaying results from marine ecosystem models, and (4) complete a demonstration application linking NEMURO models with a hydrodynamic model.

This effort will include collaboration between the Northwest and Alaska regions within NMFS, with the NOAA-sponsored ESMF project, and with international members of the PICES community. The work leverages ongoing ecosystem model development work (funded by NOAA and other sources), the ESMF technology, and HPCC-sponsored visualization and collaboration tools (SGT, ncBrowse, and others). Future work will aim toward enhanced trans-Pacific network collaboration technologies.

Problem Statement:

The role of climate change and its effects on ocean basins and their ecosystems is a research topic receiving international attention. The research is motivated by the need to predict and understand the effects of global climate change on energy cycling, ecosystems and fish production in oceanic systems and the recognition that it is essential that we develop quantitative approaches to managing sustainable marine resources. Climate change effects on marine ecosystems have received considerably less attention than terrestrial ecosystems, yet according to FAO statistics, fisheries provide one fifth of the world's human consumption of protein, and one billion people (mainly in developing countries) rely on fish as their primary source of protein.

The impact of climate change on marine ecosystems and the identification of associated processes and mechanisms remain elusive and thus the importance of the impact of variability of physical forcing and internal ecosystem dynamics on the structure and function of marine ecosystems remains unresolved in many instances. Field-based studies to establish the importance of climate change are a difficult undertaking given the complexity of even the smallest marine ecosystem. Such studies are even more difficult in continental shelf and open ocean domains where the ecosystems under consideration are not generally isolated. Another approach in determining the extent of these impacts is through the development of theoretical or comprehensive simulation models. Even though these tools are simplifications of larger more complex systems, they still remain difficult to build and use largely due to the complexity of the systems they endeavor to represent. A result of the complexity of the models used to describe climate change effects on marine ecosystems, the modeling community is changing from a collection of individual researchers investigating independent questions to international institutional teams of collaborators to develop, maintain, and execute integrated modeling systems. As a result, the individual researcher, often schooled in a single disciplinary topic, is no longer capable of mastering the entirety of the modeling system. Thus, complicated models of marine ecosystems are best developed in a collaborative setting, drawing on a diverse mix of expertise needed to effectively address the problem.

The North Pacific Marine Science Organization (PICES, http://www.pices.int) Climate Change and Carrying Capacity (CCCC) program (a regional program of IGBP/SCOR/IOC GLOBEC International) has provided a context for such collaboration. That program is now entering it's synthesis phase, during which local studies will be merged into basin-scale analyses, and single-focus studies (physics, chemistry, plankton, fish) will be linked into full system syntheses. The PICES NEMURO model (M. J. Kishi et al. 2001, J. Oceanogr. 57:499-507), together with associated fish bioenergetics models, will be the focal tool for lower trophic level analyses, providing the link between ocean physics and upper trophic level ecosystem dynamics. However, to date the NEMURO model has been used only in limited local studies, with code strongly intertwined with hydrographic models configured to local geographies. Moving forward with synthetic modeling will require disseminating the code in a form that can be used by scientists unfamiliar with its internal details, and that can be linked with a variety of physical and ecosystem models developed by independent regional research groups.

Success in ocean basin-scale ecosystem analyses will depend on the ability to integrate and adapt numerous model components in a timely fashion. Linking ocean physics and biological models is always problematic—for example, the time and space scales of physical and biological processes are different, and efficient solution of the models will reflect this with different space-time grids for various components. Besides the scientific work involved in model design, testing, and analysis, this work will require careful design of component models, in particular agreement on a modular applications interface (API) to serve as the "glue" that holds the component models together, as well as technologies to support communications among researchers around the Pacific rim.

Relationship to HPCC program objectives: The proposed work directly addresses the new "modeling frameworks" component under the Collaboration, Visualization, and Analysis theme. Aspects of the proposal also relate to "advanced enabling technologies" (application sharing and communications) under the same theme, and to the HPCC Technology Transfer theme (use of previous HPCC tools). This project would serve as a unique demonstration of ESMF in ecosystem modeling, enabling future applications outside the PICES region. Beyond HPCC, the work directly supports NOAA's climate research, ecosystem management, and ecological forecasting missions as well as NOAA's strategic goal of building sustainable fisheries.

Proposed Solution:

Overview: We propose an international collaboration to improve usability of the NEMURO model suite by integrating it within the ESMF. The NEMURO suite includes the original NEMURO model (a 1-D nutrient-phytoplankton-zooplankton model), adaptations of NEMURO to 2-D and 3-D gridded spaces, and NEMURO.FISH (the NEMURO model dynamically linked to a fish bioenergetics and population dynamics model). Main accomplishments will be: (1) re-code the NEMURO models to fully utilize ESMF superstructure and infrastructure, (2) develop API documentation and users guide for NEMURO models, (3) implement a web-based interface for displaying results from marine ecosystem models, and (4) complete a demonstration application linking NEMURO models with a hydrodynamic model. If work moves ahead of schedule, we will add additional components to the work, including (5) developing linkages to upper-level ecosystem models that directly address managed fishery and marine mammal resources.

Work will be guided by an initial planning workshop, including participation of the NEMURO developers, ESMF developers, and other scientists representing potential users of the applications. This workshop will be held on the U.S. west coast, but we have included budget to support travel for two Asian scientists. Following this initial workshop, work will proceed on adapting NEMURO and NEMURO.FISH as ESMF components, and testing the components with linkages to one or more hydrodynamic models. Final aspects of the work will include documenting the NEMURO API, presenting results in a final web-based workshop, and publishing the code and documentation on the internet.

Technical details: There are two principal technical challenges in this project: Developing a model API that allows easy interfacing to multiple physics models across trophic levels, and developing a communications interface for analyzing model results.

ESMF provides a number of services that simplify APIs to link gridded spatial models. ESMF provides a means of addressing grid scale mismatch through a structured approach, where various gridded component models are linked through coupler components, which incorporate re-gridding of modeled fields that pass from one model to another. Figure 1 illustrates one possible structure for our application using a combination of ESMF gridded model components and ESMF coupler components, embedded within an ESMF application framework (other structures are possible and will be considered in our planning workshop). Beyond these "superstructure" aspects of ESMF, the package also provides useful infrastructure including netCDF I/O, calendar, metadata, and simulation control routines.

Communication of the voluminous and multi-dimensional (5-D: x,y,z, time, state variable) output from complex models and value-added analysis requires the ability to readily manipulate and display large gridded datasets resulting from model runs. International collaboration also requires the ability to do this in real time over long distances. For this purpose, we will explore a variety of approaches developed by earlier HPCC projects, including Java-based data interfaces such as the Scientific Graphics Toolkit (SGT, http://www.epic.noaa.gov/java/sgt/index.html) and gridded data browsers (ncBrowse, http://www.epic.noaa.gov/java/ncBrowse/index.html). We will also identify a web conferencing/groupware application to use for the final project workshop.

Resources: Completing this project will require participation beyond the lead investigators (Wainwright & Megrey). We anticipate collaboration (in workshops and via e-mail) by other MODEL Team members, including NEMURO model developers, and participation of ESMF developers. All participants (except the contract programmer and technical writer funded under

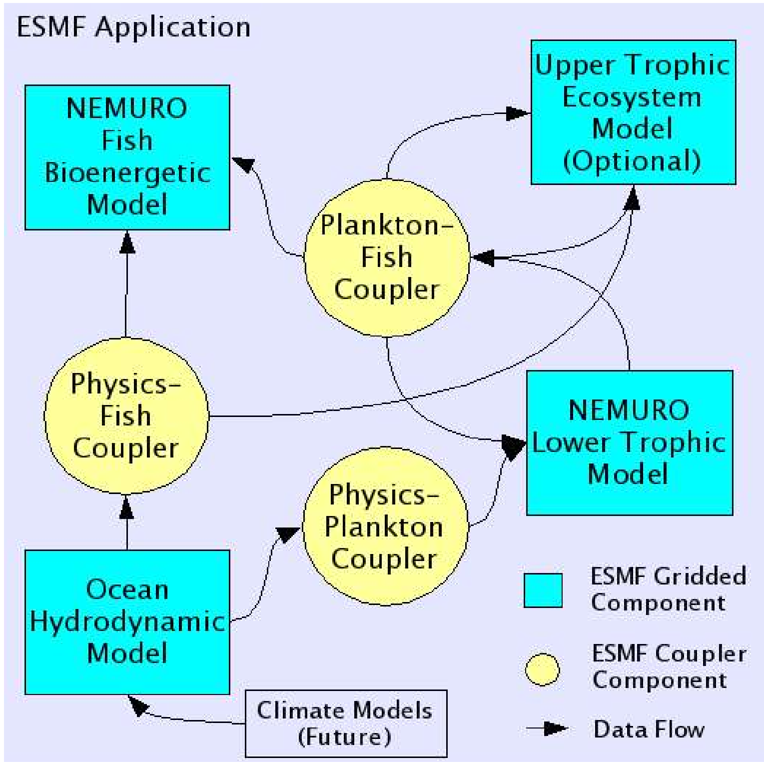

Figure 1. A possible structure of the demo application.

this proposal) will donate their time at no cost to HPCC as a matching contribution. The lead investigators will each contribute approximately one month of their time to the project as a matching contribution, as well as overhead associated with use of the NWFSC and AFSC facilities (i.e. office space, computing resources, communications (phone, fax, internet), office equipment etc.). The proposed work also leverages ongoing ecosystem model development work (funded by the NOAA FATE program, the Asia-Pacific Network for Global Change Research [APN, http://www.apn.gr.jp] and other sources), the ESMF technology, and HPCC-sponsored visualization and collaboration tools (SGT, ncBrowse, and others).

Analysis:

Rationale: Complex systems analysis requires broad collaborative effort involving multiple models across several space-time scales. Specialists in different fields (in our case, climate science, physical oceanography, biological oceanography, and fisheries) develop models for specific aspects of a problem at scales and with data definitions specific to the immediate task, but analysis of the whole system requires linking these models, with careful attention to matching of measurement units and grid scales. Additionally, there is a need for flexibility so that existing models can be applied for example in new geographic ranges, and component models can be modified without requiring changes in other system components. Our approach adapts an emerging object-oriented modeling framework (ESMF) to the problem of linking ecosystem and physics models to a variety of geographic settings.

Alternative approaches: Besides ESMF, we considered other software-integration frameworks to support PICES modeling work, including Java-based integration libraries, but found none that offered the same benefits as ESMF while allowing retention of the FORTRAN90/95 code base. The only viable alternative would be to write our own model linkage API, but that would potentially require more of a time commitment, and would result in code incompatible with emerging ocean science standards.

Benefits and risks: The immediate benefits of this work are clear: we will document and publish a suite of ecosystem analysis tools that can be readily adapted to different regions and to different approaches to modeling climate and ocean physics in different international settings. This will enable the work of the PICES CCCC program to move forward more rapidly than it otherwise would because our proposed ESMF tools would provide a language-neutral technical tool that transcends typical communication barriers as well as different scientific cultures. However, there are benefits beyond the immediate application. Documentation of the NEMURO suite of code is an immediate benefit. Broader benefits will result from proving the utility of the ESMF approach in an focal area (biological modeling) that was not intended in its original design. We hope that this will evolve into a framework useful for assessing the effects of climate change on ecosystems and biological resources throughout NOAA.

There are, of course, risks involved with this approach: we are aware of no other successful attempts to make ecosystem models "plug and play" with respect to geographic regions and underlying physics models, and the ESMF software is currently in a "proof-of-concept" stage (usable, but not complete). Using an emerging standard in its infancy, as attractive as it may seem, relies on the use of new technology which is often rife with unanticipated roadblocks to the achievement of projected milestones in a proposal such as this. Undoubtedly, we will encounter some of these in the new application of ESMF. But we do not see these as insurmountable hurdles. The ESMF team supports their work and they have recently released ESMF Version 2.0, the first release of the framework that can be used in real applications. It continues to build on earlier enhancements and includes software for representing and manipulating modeling components, states, bundles of fields, fields, grids, and arrays, as well as useful utilities for time management, configuration, and logging.

Performance Measures:

Milestones:
- Month 2 – Project staff, computing resources in place
- Month 3 – Initial planning workshop
- Month 6 – Draft release of NEMURO ESMF components
- Month 10 – Complete demo application
- Month 11 – Complete web visualization interface
- Month 12 – Final virtual workshop
- Month 12 – Publish code and documentation

Deliverables:
- ESMF Components for NEMURO and NEMURO.FISH.
- API Documentation and Users Guide for NEMURO and NEMURO.FISH.
- Web-based interface for displaying results from NEMURO models.
- Demonstration Application linking NEMURO and NEMURO.FISH with a hydrodynamic model.
- (Optional, as time allows) ESMF upper ecosystem components.