A National Oceanographic Partnership Program Award

**PARADIGM: The Partnership for Advancing Interdisciplinary Global Modeling**

Lewis M. Rothstein  
Graduate School of Oceanography  
University of Rhode Island  
Narragansett Bay Campus, Narragansett, RI 02882  
phone: (401) 874-6517 fax: (401) 874-6728 email: lrothstein@gso.uri.edu

Mark R. Abbott  
College of Oceanic and Atmospheric Sciences  
Oregon State University  
Corvallis, Oregon, 97331-5503  
phone: (541) 737-4045 fax: (541) 737-2067 email: mark@oce.orst.edu

Eric P. Chassignet  
University of Miami  
4600 Rickenbacker Causeway,  
Miami, Fl 33149-1098  
phone: (305) 361-4041 fax: (305) 361-4696 email: echassignet@rsmas.miami.edu

John J. Cullen  
Department of Oceanography  
Dalhousie University  
Halifax, Nova Scotia B3H 4J1, Canada  
phone: (902) 494-6667 fax: (902) 494-2039 email: John.Cullen@Dal.CA

Kenneth L. Denman  
Canadian Centre for Climate Modelling and Analysis  
University of Victoria  
P.O. Box 1700, STN CSC  
Victoria, BC, Canada, V8W 2Y2  
phone: (250) 363-8230 fax: (250) 363-8247 email: ken.denman@ec.gc.ca

Scott C. Doney  
Climate and Global Dynamics Division  
NCAR  
Boulder, CO 80307  
phone: (303) 497-1639 fax: (303) 497-1700 email: sdoney@whoi.edu

Hugh W. Ducklow  
Virginia Institute of Marine Sciences  
Box 1346  
Gloucester Point, VA 23062  
phone: (804) 684-7180 fax: (804) 684-7293 email: duck@vims.edu

Michael Follows  
54-1514  
Dept. of Earth, Atmosphere and Planetary Science
**Report Documentation Page**

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

<table>
<thead>
<tr>
<th>1. REPORT DATE</th>
<th>2. REPORT TYPE</th>
<th>3. DATES COVERED</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td></td>
<td>00-00-2002 to 00-00-2002</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4. TITLE AND SUBTITLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PARADIGM: The Partnership for Advancing Interdisciplinary Global Modeling</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>6. AUTHOR(S)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</th>
</tr>
</thead>
<tbody>
<tr>
<td>University of Rhode Island, Graduate School of Oceanography, Narragansett, RI, 02882</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>12. DISTRIBUTION/AVAILABILITY STATEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approved for public release; distribution unlimited</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>16. SECURITY CLASSIFICATION OF:</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. REPORT</td>
</tr>
<tr>
<td>b. ABSTRACT</td>
</tr>
<tr>
<td>c. THIS PAGE</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>17. LIMITATION OF ABSTRACT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same as Report (SAR)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>18. NUMBER OF PAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>19a. NAME OF RESPONSIBLE PERSON</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

Standard Form 298 (Rev. 8-98)
Prepared by ANSI Z39-18
A National Oceanographic Partnership Program Award

Massachusetts Institute of Technology
Cambridge, MA 02139
phone: (617) 253-5939 fax: (617) 253-4464  email: mick@plume.mit.edu

Dale B. Haidvogel
Institute of Marine and Coastal Sciences
Rutgers, The State University of New Jersey
71 Dudley Road
New Brunswick, NJ 08901-8521
phone: (732) 932-6555 x256 fax: (732) 932-8578  email: dale@imcs.rutgers.edu

Eileen E. Hofmann
Center for Coastal Physical Oceanography
Crittenton Hall
Old Dominion University
Norfolk, VA 23529
phone: (757) 683-5334 fax: (757) 683-5550  email: hofmann@ccpo.odu.edu

David M. Karl
University of Hawaii, Oceanography
1000 Pope Road
Honolulu, HI 96822
phone: (808) 956-8964 fax: (808) 956-5059  email: dkarl@soest.hawaii.edu

John C. Kindle
Naval Research Laboratory
Code 7331
Stennis Space Center, MS 39529
phone: (228) 688-4118 fax: (228) 688-5997  email: kindle@nrlssc.navy.mil

Charles R. McClain
NASA Goddard Space Flight Center
Code 970.2
Greenbelt, MD 20771
phone: (301) 286-5377 fax: (301) 286-0268  email: mcclain@calval.gsfc.nasa.gov

Dennis J. McGillicuddy, Jr.
Department of Applied Ocean Physics and Engineering
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543
phone: (508) 289-2683 fax: (508) 547-2194  email: dmcgillicuddy@whoi.edu

Richard D. Smith
Theoretical Division,
Group T-3, MS B216,
Los Alamos National Laboratory,
Los Alamos, NM 87544
Long-Term Goals

To develop an efficient, community-based coupled biogeochemical-physical modeling framework that will enable the addition of new oceanographic processes in a straightforward and transparent manner, allowing new model structures to be developed and explored as our understanding of ocean ecology and biogeochemistry improves.

To develop such a modeling framework within the context of our initial, specific overarching scientific focus: an inter-comparison study between the subtropical-subpolar gyre systems of the North Pacific and North Atlantic basins, including an explicit coastal component, with particular emphasis on understanding:

- new paradigms for physical and chemical control of plankton community structure and function,
- the consequences for biogeochemical cycling,
- the effects of sub-mesoscale and mesoscale forcing, and
- the dynamics of long-term, climate driven ecosystem regime shifts.

To meet the challenge of merging observations and models through

- advanced data assimilation techniques,
- development of interdisciplinary data products for incorporation into models, and
- application of new statistical and complex dynamical systems analysis techniques.

The merging of observations and models supports a rigorous model validation program that is central to PARADIGM.

Objectives

Our primary scientific objective is to improve our understanding of the mean state, seasonal cycle, and natural interannual to decadal variability of global and basin-scale biogeographical patterns. Why do different ecosystems reside where they do? What combination of forcing and biological responses drives the observed long-term variability and apparent ecosystem regime shifts? The intrinsic scales of ocean ecology are set by the growth and removal of phytoplankton, with time-constants of one to a few days. Our project scope must, therefore, encompass the range
of coupled dynamics of ocean ecology, biogeochemistry, and physics on scales from sub-diurnal to multi-decadal and submesoscale to global.

The project can be divided into four major scientific themes, with associated questions:

1) **Biogeochemical cycles.** What factors govern phytoplankton biomass, productivity and export, the net remineralization of organic matter below the euphotic zone, and the spatial (e.g., biogeographical regimes) and temporal (e.g., climate regime shifts) variations in these global processes? Field studies from the JGOFS era demonstrate quite clearly the critical roles for particular locations and times of multiple limiting nutrients (e.g., nitrogen, silicate, and iron), ratios of which strongly influence biogeochemical cycling. We know that physical variability and grazing modulate biological responses, and that changes in species composition and functional groups are involved. Descriptions of ecological, top-down controls and the interactions amongst these processes are not well constrained, however. Consequently, a second theme will focus squarely on ecosystem processes.

2) **Community structure.** What processes govern plankton community structure and function and how do physical-chemical-biological interactions influence biogeochemical processes in the ocean system? We begin with a widely accepted, but relatively poorly documented, two-state ocean model, with a near-uniform background state dominated by small-celled microbial plankton, and a highly episodic and variable component of larger cells (diatoms, mesozooplankton, gelatinous plankton), which contributes most of the export. The responses of key planktonic functional groups (nitrogen fixers, calcifiers, etc.) are also important because they influence differentially the cycling of nutrients and carbon. The two-state ocean model rests strongly on the hypothesis that physical perturbations drive the proliferation of larger cells and resultant enhanced export. Our third theme examines this forcing.

3) **Scales of physical forcing.** How do mesoscale and sub-mesoscale physical variability impact ecosystem fluxes and community structure? Mesoscale variability and disturbance are fundamental aspects of the marine system, not simply noise. The scientific details of how transient ecosystem response to perturbations rectify into large-scale or long-term variability in ecosystem structure and biogeochemical cycling are not well known, however. Present computational constraints prohibit full numerical resolution of all scales of interest, requiring technical advances in multi-scale grid-nesting, heterogeneous and adaptive grids, and subgridscale parameterizations. These and other constraints on interdisciplinary modeling provide the focus for our fourth theme.

4) **Advanced interdisciplinary models.** How do we best merge observations and models? Biogeochemical and ecosystem models are powerful tools to analyze the behavior and dynamics of complex marine ecosystems, but at their core are data driven. Unlike ocean physics, we do not have a Navier-Stokes law for biology. However we do have strong ‘first principles’ constraints, e.g., size vs. respiration, nutrient limitation vs. stoichiometry, etc., so it is possible to develop detailed models based on fairly general biological characteristics such as size and functional groups. The new models will predict much more than chlorophyll or nitrogen. Progress in merging observations with model predictions will require new statistical and complex dynamical systems analysis techniques, the development of new (e.g., bio-optical, multivariate) data
products for incorporation into models, innovative data visualization, rigorous model-data evaluation, and greater reliance on data assimilation.

Approach
PARADIGM is a group of 16 scientists committed to building and deploying new, advanced models of ecology and biogeochemistry for understanding and predicting the future states of the ocean. The group combines expertise of observers and modelers, ecologists and physicists, biogeochemists and numerical specialists. Our overall scientific goal is a rigorous, model- and observation-based intercomparison of ecosystem/biogeochemical dynamics of the North Pacific and Atlantic subtropical - subpolar gyres. Our central objective is creation of new global ocean biogeochemistry community models, comprising complex ecosystem dynamics based on functional groups (e.g., Archaea, diatoms, copepods, gelatinous predators), individual keystone species (e.g., Trichodesmium, Euphausia superba) and multielement limitation and cycling (e.g., C, N, P, Si, Fe). The physical model platform is composed of a hierarchy of mature, general circulation models each the focus of extensive community model development programs. PARADIGM models will be capable of emergent behavior testing the hypothesis that fundamental regime shifts occur in response to climate change. Community models will be developed by interdisciplinary teams devoted to five program elements: (1) data fusion, synthesis and validation; (2) ecosystem model development; (3) high-resolution basin scale and regional process studies; (4) focus sites (i.e., regional test-beds) and (5) numerical method development (including data assimilation).

Work Completed
The program is just finishing its first 6 months of existence and hence has no significant work completed at this time.

Results
Again, the program is just completing its first half year of a five year, renewable program and has no significant results to report at this time. This report does come just two weeks ahead of our first annual PI meeting, to be held at Woods Hole Oceanographic Institute 29-31 Oct, 2002.

Impact and applications
Economic Development
PARADIGM will be learning much about the biogeochemical physical “pathways” (i.e. the circulation of subduction and ventilation) towards the deep ocean and as such might, in time, be a useful source of unbiased scientific knowledge for informing the government or private sector of ecosystem impacts for sequestering pollutants into the deep ocean.

Quality of Life
PARADIGM will develop new community models of ocean biogeochemistry and ecology on global scales, comprising complex ecosystem dynamics based on functional groups (e.g., Archaea, diatoms, copepods, gelatinous predators), individual keystone species (e.g., Trichodesmium, Euphausia superba) and multi-element limitation and cycling (e.g., C, N, P, Si, Fe). These models will include new parameterizations of mesoscale and submesoscale processes that are especially important in biological/physical coupling. Data assimilation and
data fusion will be used to improve model formulation and to validate model performance. New approaches to software development will be used to simplify the addition of new ocean processes. The models will be capable of emergent behavior, testing the hypothesis that fundamental domain shifts occur in response to climate change.

PARADIGM will focus entirely on the lower trophic levels and as such would, in time, become a valuable source of scientific information regarding the health management of global ecosystems at the higher trophic levels that feed on the biogeochemistry that is the focus of PARADIGM.

Science Education and Communication
PARADIGM will improve linkages between modelers and field oceanographers by creating an environment where model assumptions can be explored, model performance rigorously evaluated, and new ideas and hypotheses formulated and tested. Through regular interactions, data visualization, and focused workshops, PARADIGM will serve as an intellectual hub for the study of ocean ecology and biogeochemistry with numerical models as the tool. By making such models more transparent to the non-modeler, we will enable the study of complex, global-scale processes in a rigorous open manner. All of the PARADIGM investigators have a deep commitment to education at the undergraduate, graduate and postdoctoral levels and intend to include these young scientists in our program in a meaningful way.

Transitions
Economic Development
PARADIGM could be a useful source of expert scientific information for informing the government on the environmental impacts of the recently discussed potentials of ocean carbon sequestration. Our program is only in its first year; this information could become available towards the end of the five-year program.

Quality of Life
Because of our focus on the fundamental mechanisms of the lower trophic levels of global ocean biogeochemistry and its relationships with global climate change, PARADIGM will be in position to eventually make a contribution to debates about our national fisheries programs.

Science Education and Communication
To benefit from relationships outside our consortium, a fundamental objective will be to make all of our research widely available to the scientific community, both through traditional mechanisms (e.g., workshops) and innovative modes of communication (web-based interactive exchanges). This includes the distribution of forward model and data assimilation products, computational algorithms, etc. through workshops, summer schools, etc. The entire oceanographic community will be able to access our model software.