
**EXTERNAL REVIEW OF THE
COOPERATIVE INSTITUTE FOR CLIMATE SCIENCE**

**PRINCETON UNIVERSITY
PRINCETON, NEW JERSEY**

BY

THE CICS REVIEW PANEL

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**SUBMITTED TO THE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
SCIENCE ADVISORY BOARD**

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EXECUTIVE SUMMARY

An external review of the research, education, and outreach programs of the Cooperative Institute for Climate Science (CICS) at the Princeton University (Princeton) was conducted on January 18-19, 2006 at Princeton University. Guidelines for conducting the review were provided by the Office of Oceanic and Atmospheric Research (OAR) within the National Oceanic and Atmospheric Administration (NOAA). The review was conducted under the auspices of the NOAA Science Advisory Board (SAB) and, therefore, is subject to the requirements of the Federal Advisory Committee Act (FACA).

The CICS program at Princeton is led by Dr. Jorge Sarmiento, Professor of Atmospheric and Oceanic Sciences. Professor Sarmiento is also co-director of the Carbon Modeling Consortium at Princeton. The CICS external review committee surmised, in general, that the program is one of pride and a flagship for NOAA's Cooperative Institutes. CICS is a valuable asset to NOAA and the research community. CICS is doing very well and Princeton should have the liberty to decide if they want to change the current activities and scope of the program. The constituents of the CICS program should have the ability to change their identity and grow in areas that would mutually benefit NOAA's mission and Princeton's research activities.

After an intensive review of the CICS program at Princeton, the external review panel (Appendix A) found strengths and provided constructive criticisms of the existing program. Besides the praise mentioned above, a summary of the strengths of the CICS program include: [1] The CICS Director, Dr. Jorge Sarmiento, has done an excellent job, yet he receives no salary support as CICS Director; [2] outstanding science is performed with highly talented scientists and students; [3] excellent collaborations exist between the University and the NOAA Geophysical Fluid Dynamics Laboratory (NOAA/GFDL); [4] the unrivaled ability to perform joint biogeochemical modeling; [5] students and postdoctoral scientists are in a vibrant learning environment and are very proud of being at Princeton and NOAA; [6] The GFDL-based modeling in ocean and atmospheric sciences provides an outstanding postdoctoral and graduate student training, managed by CICS's Atmospheric and Oceanic Sciences (AOS) division.

After an objective review of the CICS program, the external visiting committee was able to identify specific recommendations and suggestions to assist CICS to help the program to expand naturally into areas to increase the scientific impact of Princeton/NOAA CICS research. Based on the information presented in the review, the panel has six specific recommendations that are believed may strengthen CICS including: [1] that the director, Princeton Professor Sarmiento, is provided increased management support to better focus and lead CICS activities; [2] that CICS support is too strongly tied to the one source of NOAA funding through GFDL and CICS and should continue to branch out to other NOAA constituents, other federal agencies, or private foundations; [3] that Princeton does not provide enough support in the form of a main campus presence for CICS and the communication between the Forrestal and the Main Campus might be facilitated by small actions, such as main campus parking space for CICS employees, to a large action, such as a main campus building; [4] that CICS lacks a critical mass in paleoclimate analysis and modeling to be a main theme in their overarching scientific mission; [5] that CICS lacks the funding support in integrating social and physical science to address policy decision making. The collaborations with the Woodrow Wilson School should be embellished, encouraged, and enhanced; and [6] that Princeton

should determine whether it wishes to aggressively advance CICS as a mechanism for wider collaboration with more elements of NOAA and the nation, or continue to focus and utilize CICS as an effective joint venture with NOAA/GFDL.

I. OVERVIEW OF CICS

CICS is a NOAA Cooperative/Joint Institute (CI), sponsored by NOAA's OAR, at Princeton University. It is currently directed by Professor Jorge Sarmiento, with Professor Geoffrey Vallis as Associate Director. CICS was established in 2003, but is based on a 38-year long-standing cooperative program between NOAA's Geophysical Fluid Dynamics Laboratory (GFDL) and Princeton University. CICS provides a framework at Princeton University for facilitating and coordinating collaborative research and education between GFDL and Princeton University, as well as building ties with other NOAA laboratories, and providing a conduit for individual research projects funded by NOAA in response to proposals submitted by individual investigators to Announcements of Opportunity. The primary activity of CICS is joint research and education between GFDL and Princeton University organized under two major components:

(1) Cooperative Research

Collaborative research between the AOS Program of Princeton University and GFDL, wherein NOAA supports postdoctoral fellows, visiting scholars, long-term researchers, and graduate students who work predominantly with scientists at GFDL. The AOS Program, currently directed by Professor George Philander, has 16 faculty members, 11 of whom are GFDL scientists with appointments of Lecturer or Lecturer with Rank of Professor at Princeton University. The Cooperative Research program has been an integral part of the AOS program for thirty-eight years, and remains the key to the long-term successful collaboration between Princeton and GFDL.

(2) Princeton Climate Center (PCC)

A collection of research initiatives by Princeton University faculty, as well as associated institutions, that provide particular expertise not available at Princeton. The associated institutions include Rutgers University, Harvard University, Johns Hopkins University, and the University of New Hampshire. The research in this component of CICS is focused primarily around development of the new GFDL Earth System model and the use of this model to address a wide range of research problems. The strengths that members at Princeton University and the associated institutions bring to the consortium in CICS are in the areas of biogeochemistry, physical oceanography, paleoclimate, hydrology, ecosystem ecology, climate change mitigation technology, economics and policy, and coastal oceanography. The coastal oceanography component is provided by collaborations with Rutgers University. Research projects sponsored under this component of CICS are managed through the PCC under the Princeton Environmental Institute (PEI).

CICS has four research themes including: (1) earth system studies and climate research, (2) biogeochemistry, (3) coastal processes, and (4) paleoclimate. The Cooperative Research program in AOS is focused primarily on the first of these themes, whereas PCC research addresses all four.

CICS has a small staff: its Director, Associate Director, and a half-time administrative assistant. The

AOS Program and PEI contribute the majority of the staff support for CICS. During the one-year period between July 1, 2004, and June 30, 2005, covered by CICS's most recent annual report, CICS supported 20 postdoctoral fellows, 20 PhD research scientists and senior fellows, 12 graduate students, 6 faculty members (summer salary; 3 at Princeton University and 3 at other institutions receiving CICS support), and 3 technical staff members, as well as summer support for a middle school science teacher who was an instructor at a science teacher preparation program at Princeton University for teachers in the third through the sixth grade. The research scientists and graduate students were all supervised by CICS Fellows, which consist of all AOS and PCC faculty members that are involved in CICS research activities. CICS scientists were responsible for the publication of 47 peer-reviewed papers, 3 book chapters, and 1 PhD thesis. CICS funding during this period was \$3,930,638.

The following sections describe the four mandatory elements that the NOAA SAB requires be addressed in all CI reviews. The final section is a summary of the findings and recommendations.

II. SCIENCE PLAN

A. Vision

CICS was created in October 2003, as the culmination of a successful 38-year collaboration between Princeton University scientists and GFDL to produce oceanic and atmospheric models, research climate and biogeochemical cycling, and to educate graduate students. CICS was founded by expanding the pre-existing AOS cooperative agreement into a cooperative institute. The vision of CICS is:

To be a world leader in understanding and predicting climate and the co-evolution of society and the environment – integrating physical, chemical, biological, technological, economical, social, and ethical dimensions – and in educating the next generations to deal with the increasing complexity of these issues.

Creation of the CI provides increased opportunities for scientific partnerships and collaborations between the University, GFDL, and NOAA. Prior to CICS, the collaboration with GFDL took place primarily through a postdoctoral and visiting scientist program, with the main purpose of attracting postdoctoral scientists to work with GFDL scientists. CICS allows for a greater role by the University and thus a broader scope of activities, as described in this report.

The panel's awareness of the diversity of important interactions among elements of the Earth System provides both an unprecedented opportunity and a unique challenge for NOAA. The unprecedented opportunity is to incorporate the linkages of the Earth System into models that forecast a myriad of environmental phenomenon including weather, natural hazards (e.g., floods), air quality, climate forcing, seasonal climate, nutrient inputs into coastal areas, coastal storm damage, and centennial-scale climate change including extremes. These models could have the capacity to assimilate the growing diversity of observations and to focus on scales ranging from the globe (i.e., a fully coupled Earth System model) to the regional and local scales relevant to many stakeholders. NOAA's unique challenge is to work toward an integrated understanding of the earth system in the face of an

increased complexity that comes from coupling models of different kinds of processes together. This may require NOAA to take the lead in Earth System modeling. CICS contributes expertise in a wide range of areas that will help NOAA to meet this challenge.

B. Relationship to NOAA's Strategic Plan

NOAA's current Strategic Plan identifies four Mission Goals: (1) protect, restore and manage the use of coastal and ocean resources through ecosystem-based management, (2) understand climate variability and change to enhance society's ability to plan and respond, (3) serve society's needs for weather and water information, and (4) support the nation's commerce with information for safe, efficient and environmentally sound transportation. The research carried out by CICS is directly relevant to the first three of these goals and indirectly to the fourth.

Examples of the ways in which CICS supports these NOAA goals include:

- Engaging in world-class scientific research that helps to identify important processes with a potential to impact physical climate or an important biogeochemical cycle;
- Collaborating with scientists at GFDL and elsewhere to develop representations of these processes that can be included in GFDL's models for use in assessment;
- Working to constrain both the models and the processes which they represent using the best available data through extensive collaboration with other NOAA laboratories (in particular the Earth System Research Laboratory (ESRL), Pacific Marine Environmental Laboratory (PMEL), and the Atlantic Oceanographic and Meteorological Laboratory (AOML)) as well as with academic partners and other agencies such as NASA, DOE, and NSF;
- Applying research results to problems of societal relevance, in concert with projects such as Princeton's Carbon Mitigation Initiative and programs such as the Science Technology and Environmental Policy Program at the Woodrow Wilson School;
- Helping GFDL take advantage of new developments in computer science in order to utilize computational resources more efficiently;
- Supporting the training and involvement of the next generation of scientists and researchers in NOAA research.

NOAA's Geophysical Fluid Dynamics Lab has a long history of developing tools to analyze, understand and predict the physical components of the climate system, tracking the flows of momentum, heat, and moisture through the atmosphere, ocean, and cryosphere. As a result, the bulk of the GFDL's (and CICS's) research sits within NOAA's Environmental Modeling Program under the Weather and Water Mission Goal, and within the Climate Predictions and Projections Program under the Climate Mission Goal. A significant amount of CICS research is devoted to exploring climate variability and change, advancing such performance objectives as "describe and understand the state of the climate system", "improve climate predictive capability", and "reduce uncertainty in

climate projections through timely information on the forcings and feedbacks”.

It is increasingly clear, however, that climate is more than a purely physical system and there are critical interactions with other elements of the Earth System. For example, biogenic and anthropogenic aerosols, greenhouse gasses, and land use changes can have important roles in altering global and regional climate. It is also clear that in order to achieve NOAA performance objectives such as “understand and predict the consequences of climate variability and change on marine ecosystems” and “increase the number and use of climate products and services,” it will be necessary to integrate models of marine and terrestrial ecosystems, hydrology, and air quality into GFDL’s physical models.

CICS has thus tried to advance the predictive understanding of the physical climate system while developing tools to analyze the two-way interactions between the climate system and other Earth System components. Additionally, CICS supports cross-cutting infrastructure development to improve the performance and usability of GFDL’s computer codes, enabling more efficient use of resources.

CICS research is also closely aligned with the goals of the U.S. Climate Change Science Program (US-CCSP) that was issued in July 2003. In particular, CICS research on improved estimation of carbon source and sinks is directly prescribed in the Program’s Science Strategic Plan.

C. Major Scientific Themes - Goals and Objectives

CICS goals are to foster research in four thematic areas in support of NOAA’s mission and strategic goals: Earth System Studies/Climate Research, Biogeochemistry, Coastal Processes and Paleoclimate.

1. Earth System Studies and Climate Research

The goal of the Earth System Studies and Climate Research theme is to create improved climate simulation tools and use them to study the sources of climate variability. Research within this theme generally takes place at two levels. At the individual or small-group level, scientists, sometimes with post-docs and graduate students, may investigate processes and dynamics and write research papers accordingly. At the second level, these activities come together synergistically in model development and application activities that combine the expertise of several individuals in larger groups and teams that work together on a single goal.

2. Biogeochemistry

Princeton University has a strong core of expertise in biogeochemical cycling, with major research efforts in carbon cycling, nitrogen cycling, trace metal chemistry, and air quality. CICS seeks to link this expertise to the climate, atmosphere, and ocean modeling capabilities at GFDL to build predictive understanding of the whole earth system, and to expand the range of applications of climate models. This theme is currently focused around the development of the land and ocean biogeochemistry components of the Earth System model. The new model components are being used to study the causes and variability of land and oceanic carbon sinks, to explore the linkages between climate change and air quality, and to develop a data analysis system for carbon that will provide improved estimates of the spatial distribution of carbon fluxes.

3. Coastal Processes.

The coastal oceans are being severely impacted by human activities and climate change, and these impacts will grow with time. Traditionally, the main models used for climate prediction at GFDL have not included processes like tides and bottom boundary layers that play a dominant role in the dynamics of the coastal zone, nor have they had the lateral resolution to fully represent physical, geochemical and biological processes on the narrow continental shelves.

4. Paleoclimate.

CICS' Paleoclimate group combines GFDL's expertise in climate modeling with Princeton's experience in empirical and theoretical analyses of paleoclimate to investigate paleo-events that have implications for future climate response. These include the changing response of the climate to solar insolation forcing, the influence of tropical ocean-atmosphere states on climate, and the influence of freshwater fluxes and temperature changes on ocean circulation. Specific research foci at present are: [1] exploring tropical triggers for large-scale rapid climate change; [2] Exploring mechanisms for past changes in oceanic vertical exchange; and [3] exploring mechanisms for significant and frequently rapid past changes in atmospheric carbon dioxide.

D. Identifying and evaluating themes

1. Identification of themes

The four science themes were identified during the formation of CICS. They represent the convergence of research interests between Princeton University faculty and GFDL, with the addition of a coastal oceanography initiative to develop a crucial area in which neither Princeton nor GFDL had existing expertise.

2. Criteria Used to Measure Progress in Accomplishing Goals and Objectives

Success is judged by the review team by reviewing the scientific elements and provide and assessment of NOAA's interest on [1] quality, creativity, integrity, and credibility; [2] timeliness, scale and scope; [3] science connected to the application and operational implementation of policy; [4] capacity-building; [5] education; [6] efficiency; [7] social science integration; and [8] diversity. The CICS themes were only decided upon in 2003 and continue to be the primary criteria for deciding what research CICS will support.

3. Emerging thematic areas

CICS is considering a new initiative to focus some of its biogeochemistry resources on NOAA's Ecosystem Mission Goal to "protect, restore, and manage the use of coastal and marine resources through an ecosystem approach to management." The new CICS initiative on coastal ocean processes provides a framework on which to base a study of coastal resources; and the CICS Earth System ocean biogeochemistry model could provide a basis for examining larger scale marine resource issues. Funding for a workshop on fisheries has been provided. CICS also plans to examine how it might deploy some of its resources to contribute to research in rapid climate change in collaboration with Columbia University's cooperative institute, CICAR.

4. Scientific partnerships

(a) Relationship to the OAR Laboratories and other NOAA entities.

CICS is collocated with NOAA's GFDL on Princeton University's Forrestal Campus. The relationship between Princeton University and GFDL is the foundation on which their successful partnership has flourished, as demonstrated by the far-reaching impact that the Ph.D. and Post-Doctoral alumni of this program have had on this field worldwide. CICS evolved in 2003 out of a long-standing institutional agreement between the United States Department of Commerce and Princeton University that began in June 1967, three years before the National Oceanic and Atmospheric Administration came into existence. The current cooperative agreement award covers the period July 1, 2002 through June 30, 2007.

CICS's research interests are assets to those of NOAA and GFDL. In addition to its collaborations with GFDL, CICS scientists working on global carbon cycle issues under the Biogeochemistry theme have extensive interactions with scientists at ESRL, PMEL, and AMOL of NOAA. ESRL is presently providing \$155,200 to Sarmiento to support his research on ocean and atmospheric inverse modeling for global carbon flux determination. CICS planned and carried out a workshop on the global carbon cycle that was held at Princeton University in June 2005, and provided NOAA scientists working on the global carbon cycle an opportunity to discuss their joint research.

(b) Formal procedures for joint planning.

Joint planning is carried out through two committees, as well as regular interactions between CICS and GFDL Directors. The CICS Director is advised by an *Executive Committee* which consists of a subset of CICS Fellows and provides advice on the development of basic scientific themes as well as the preparation of proposals and the allocation of resources. Members of this committee include the Director of AOS, representative faculty members from the AOS Program, the CICS Director and Associate Director, and representative faculty members of the PCC Advisory Committee. The AOS faculty members are primarily GFDL scientists.

GFDL scientists and Princeton University faculty jointly chair and staff the *Visiting Scientist Selection Committee*. This is the committee that evaluates applicants to the collaborative post-doctoral program. Each year, more than two-dozen Princeton University post-doctoral scientists and one dozen Princeton University Graduate Students work or learn at GFDL in partnership with government scientists.

Joint planning and determination of climate science and modeling goals are achieved through regular meetings of the Executive Committee and more informal meetings between the GFDL Director and the CICS Director throughout the year. These policy level discussions then shape the decisions made at the Visiting Scientist Selection Committee and guide the types of research initiatives to be undertaken. These plans are reflected in GFDL's contribution to NOAA's annual planning and budgeting process, by which NOAA prioritizes and funds its research activities.

III. SCIENCE REVIEW

CICS has four science research areas including: (1) earth system studies and climate research, (2) biogeochemistry, (3) coastal processes, and (4) paleoclimate. All of these research areas provide high caliber research. The review team uses these scientific assessment elements for NOAA's interest in [1] quality, creativity, integrity, and credibility; [2] timeliness, scale and scope; [3] science connected to the application and operational implementation of policy; [4] capacity-building;

[5] education; [6] efficiency; [7] social science integration; and [8] diversity.

CICS Earth System Studies and Climate Science Research

Earth System modeling at GFDL and in CICS is now emerging from an intense period of model development during which they have produced fundamentally new atmospheric, oceanic and land models, coupled models, chemistry-radiative forcing models, cloud resolving models with new microphysics, and a non-hydrostatic limited area model. These models are already producing useful results as the group works on creating new and more sophisticated tools for increasingly realistic representation of the processes and interactions in the Earth's climate system.

With the new and more sophisticated model tools, CICS is pursuing a number of topics in climate dynamics that will lead to both improved understanding of the climate system itself, and to further improve models in the future. Researchers are investigating cloud and aerosol processes and land-surface heterogeneity to improve parameterizations of these factors in models. At the same time, model simulations are providing insight into the dynamical processes controlling climate variability and large-scale ocean and atmospheric circulation. Discussions are ongoing about adding an additional activity focused around modeling of land ice, which has the potential to play an important role in sea level rise.

CICS is also confronting models with observations in order to diagnose problems and judge reliability. The ability to simulate the observed climate, and its variability, with reasonable accuracy is essential for an accurate climate modeling system. That variability arises from and is moderated by a host of factors, including ENSO, volcanic eruptions, the changes in the radiatively-active short-lived species and their climate forcing, clouds and the hydrologic cycle, soil moisture, interdecadal oceanic variability, and the glacial-interglacial cycles of the Pleistocene. These all represent distinct challenges that must ultimately be addressed simultaneously by a successful Earth System model. CICS is well posed to pursue this ambitious, yet needed, modeling challenge.

CICS Biogeochemistry Science Research

CICS work on biochemical modeling is of the highest caliber and must continue. A particular emphasis has been the addition of nutrient-cycling to the land and ocean models, which provides important controls on biological productivity and carbon uptake. The new capability will be used to investigate key issues such as the causes of the current terrestrial carbon sink and the impacts of global warming on ocean carbon dioxide (CO₂) uptake and biology.

CICS is also building a data inversion capability for their models of the carbon cycle that integrates data from flask stations, tall towers, eddy correlation towers, shipboard ocean transects, and forest inventories. The goal is to provide ongoing estimates of the air-sea and land-atmosphere CO₂ fluxes particularly over North America.

Biogeochemistry is an area of great strength at Princeton University and critical importance for GFDL as well as NOAA as a whole, with Princeton making major contributions to both the development of the GFDL Earth System Model and the estimation of carbon fluxes (with ESRL support). CICS funding for research in this area is presently very strong, but also potentially vulnerable in that it depends on GFDL and ESRL and might be more exposed in times of budget cutbacks when protection of core laboratory activities becomes a priority. CICS should work with

NOAA and GFDL to find a solution to ensure this vulnerability is mitigated.

CICS Coastal Processes Science Research

CICS has recently initiated a collaborative project with Rutgers University that will enable the development of tools that link coastal models to global climate models. These linked models will be used to provide the best scientific information possible to decision makers, resource managers, and other users of climate information. To address the specific research questions, the project will use a multi-disciplinary approach, including analyses of *in situ* and remotely obtained data sets, circulation modeling, biogeochemical models with explicit carbon chemistry, and data assimilation techniques using dynamical and/or biological models. The specific objective of this theme is to advance NOAA's Ecosystem Mission Goal, to "protect, restore, and manage the use of coastal and marine resources through an ecosystem approach to management." While this theme is newer to CICS, CICS expertise and Rutgers University partnership make it a viable and valuable NOAA asset.

CICS Paleoclimate Science Research

CICS' Paleoclimate group combines GFDL's expertise in climate modeling with Princeton's experience in empirical and theoretical analyses of paleoclimate to investigate paleo-events that have implications for future climate response. These include the changing response of the climate to solar insolation forcing, the influence of tropical ocean-atmosphere states on climate, and the influence of freshwater fluxes and temperature changes on ocean circulation. The review panels' recommendation is that these present CICS' activities should be continued to be pursued because of NOAA's climate mission and developing a comprehensive predictive capability of the processes and feedbacks. A critical evaluation of the depth of Princeton's Paleoclimate capabilities should be conducted. The paleoclimate expertise in CICS' should be bolstered or continued collaborations with other institutions should continue.

CICS science themes demonstrate excellence in almost all of the NOAA assessment criteria including: [1] quality, creativity, integrity, and credibility; [2] timeliness, scale and scope; [3] science connected to the application and operational implementation of policy; [4] capacity-building; [5] education; [6] and efficiency. Some improvements could be added to [7] social science integration and [8] diversity. The CICS biogeochemistry research plan is a perfect match for NOAA's Strategic Plan

IV. SCIENCE MANAGEMENT PLAN

The committee reviewed the new research opportunities for CICS, the administration and human resource demographic structure, and financial health of CICS. The committee endorses the new intellectual opportunities identified by CICS, which will strengthen CICS ability to serve NOAA's ecosystem and climate mission goals. The committee also identified issues that required attention in future management of CICS.

A. Intellectual Opportunities

CICS encourages Princeton scientists to propose new intellectual opportunities throughout the year. The most important example of an "intellectual opportunity" was the recent decision to form an Integrated CICS Land Model Development Team. Although there has been substantial progress improving the representation of hydrological and carbon cycling in the GFDL land models, and also

considerable progress on nutrient cycling, there is still a need for integration provided by CICS. Several of the most important feedbacks between the terrestrial biosphere and climate cannot be represented without fully interactive models of nitrogen (N), phosphorus (P), carbon (C), and water. A second example of a new intellectual opportunity was the recent decision of CICS to provide \$114,500 to Prof. Dale Haidvogel of Rutgers University using FY'06 funds to support the development of a coastal model.

B. CI Management

CICS's three science management tasks are summarized below and illustrated in Figure 1 along with the University context within which they fit. This structure is based on similar arrangements at other NOAA Cooperative Institutes. It accommodates innovative scientific research within the academic institute while fostering strong collaboration and the exchange of ideas with GFDL. It also simplifies the administrative management and oversight of the Institute's diverse research activities.

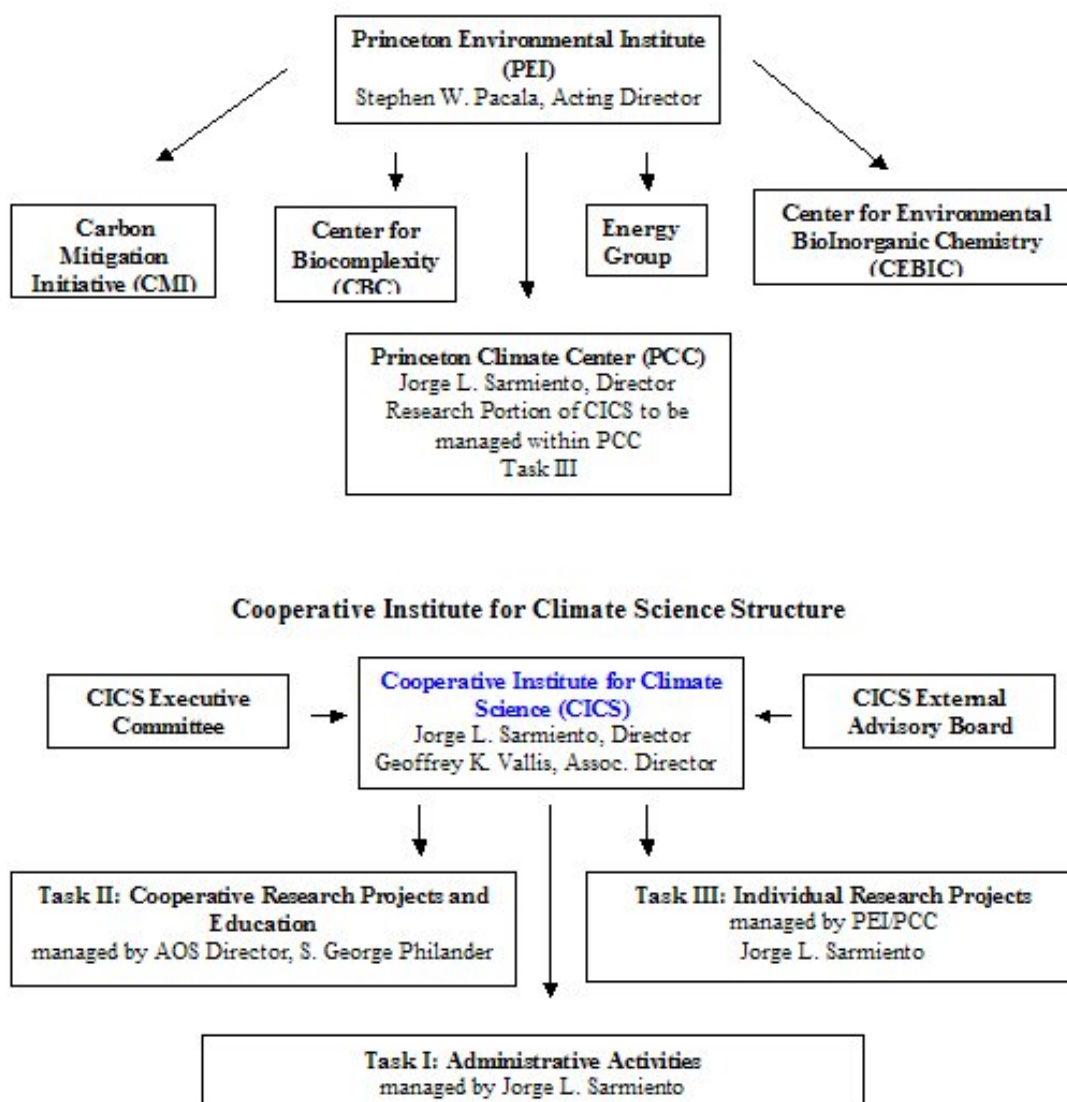


Figure 1. Organizational Structure of CICS and related Princeton University Research Activities.

CICS provides an efficient administrative framework for the research support that NOAA provides to Princeton University. The recent increase in the amount and diversity of funding Princeton University receives from NOAA, as well as the potential for further growth, made it opportune to be organized under the umbrella of a Cooperative Institute organizational structure.

1. Task I: Administration

This task covers the administrative functions of the Institute, including support for the Institute Director and an administrative assistant. As chief administrator of the Institute, the Director is responsible for managing the budget and issuing the Institutes' annual technical reports. The director also provides scientific leadership for the institute by coordinating research activities, with the guidance from the Executive Committee, setting research priorities, and fostering collaboration between NOAA and CICS scientists. The Director maintains links with other NOAA CIs and represents CICS at their periodic meetings. The administrative assistant helps the Director in administrative responsibilities. The AOS Program and PEI provide other technical, financial and administrative assistance.

The Director of CICS is recognized by the Provost of Princeton University as the lead for the interactions between NOAA and GFDL. Subsequent appointments will be decided upon by the Executive Committee of CICS in consultation with the PEI Director and Chair of Geosciences, and affirmed by the Provost. The Director will be a faculty member with strong links to both the AOS Program and PEI, and is responsible for ensuring that CICS is achieving its goals. PI driven research projects funded under the CICS agreement may have independent PI's.

An *Executive Committee*, consisting of a subset of the CICS Fellows, advises the Director and Associate Director on the development of basic scientific themes for projects as well as the preparation of proposals and allocation of resources. This committee consists of the Director, Associate Director, faculty members from the AOS Program, and the Director and faculty members from PCC. The present members of the Executive Committee are:

AOS Faculty

- George Philander (AOS Director)
- Isaac Held
- Hiram Levy
- V. Ramaswamy
- Geoffrey Vallis (Associate Director of CICS)

PCC Faculty

- Jorge Sarmiento (PCC Director and Director of CICS)
- Denise Mauzerall
- Michael Oppenheimer
- Stephen Pacala
- Ignacio Rodriguez-Iturbe

An *External Advisory Board* consists of representatives from NOAA and three senior scientists independent of NOAA. This Board will convene annually to review CICS and to make

recommendations regarding new and existing scientific program areas, research themes to be pursued by CICS, and methods to improve coordination of research programs with other institutions or agencies. NOAA representatives on the Board are chosen from all or some the following:

- Deputy Assistant Administrator of the Office of Atmospheric and Oceanic Research/NOAA
- Director of GFDL/NOAA
- Director of the Office of Global Programs/NOAA
- Leader of one other NOAA lab such as ESRL
- Representatives of NOAA at invitation of AA or director of GFDL

The CICS Executive Committee in consultation with the PEI Director and GEO Chair determines the external membership of the Board. Present members of the External Advisory Board are:

- Jeffrey T. Kiehl – Director of NCAR’s Climate Modeling Section
- Chet Koblinsky – Director of NOAA’s Climate Program Office
- Ants Leetmaa – Director of NOAA’s Geophysical Fluid Dynamics Laboratory
- A.R. Ravishankara – Acting Director of Chemical Sciences Division, NOAA’s Earth System’s Research Laboratory
- Dave Schimel – Senior Scientist at NCAR’s Terrestrial Sciences Division
- Peter Schlosser – Professor at Columbia University’s Earth and Environmental Science Department

The budget for Task I activities provides support for the core administrative activities of CICS. The present base-funding request provides support for 6 months of administrative assistant time to help in administering the Institute. The AOS program and PEI share in the administrative costs by providing additional funds to cover 6 months of administrative assistant support and an additional 2.5 months for the director. Princeton University waives the indirect cost recovery (normally 58%) on the entire Task I budget.

In addition to salaries, the Task I budget covers funds for the Director and the administrative assistant(s) to attend the annual Joint Institute meeting. Funding for computer equipment to facilitate the management of the Institute, office supplies, and for the cost of publishing CICS reports is also included.

2. Task II: Cooperative Research

This task provides for specialized support to scientists who are employed by Princeton University but located at GFDL. These CICS employees, typically postdoctoral fellows, visiting scholars, or research staff and scholars, are hired to enhance the technical and scientific expertise at GFDL required to execute collaborative CICS projects, or to address needs that require specific expertise not available at GFDL. Postdoctoral fellows constitute the bulk of the Research Program and are normally supported for one or two years. Visiting scholars, who are established scientists with positions elsewhere, may be appointed to the Program for periods from a few days to one year. Short-term visitors are normally supported with travel funds, whereas long-term visitors are afforded an appropriate University position. Finally, under exceptional circumstances, a few scientists may

be supported on a continuing basis, after consultation with the GFDL Director.

This task also supports a program for advanced graduate students that support Ph.D. thesis work consistent with the CICS themes and under the mentorship of GFDL. The Princeton AOS Program typically has an enrollment of 12-18 graduate students engaged in research and study toward a Ph.D. degree. If the focus of a student's research is deemed relevant to the scientific objectives of the Research Program and NOAA, such students are offered positions as Assistants-in-Research (AR) in the Cooperative Research Program.

The AOS Program is the platform for carrying out the education and Cooperative Research project tasks and for involvement of GFDL staff in educational and research activities. The AOS Program is an autonomous Program within the Geosciences Department, with a Director appointed by the Dean of Faculty, currently George Philander. Faculty members in the AOS Program are:

Faculty

- Leo Donner GFDL
- Stephen Garner GFDL
- Anand Gnanadesikan GFDL
- Robert Hallberg GFDL
- Isaac Held GFDL
- Ngar-Cheung Lau GFDL
- Ants Leetmaa GFDL
- Hiram Levy GFDL
- Sonya Legg AOS
- Isidoro Orlanski GFDL
- S. George Philander GEO
- Jorge Sarmiento GEO
- V. Ramaswamy GFDL
- Geoffrey Vallis AOS

Associated Faculty

- Michael Bender GEO
- Denise Mauzerall WWS
- Michael Oppenheimer GEO and WWS
- Stephen Pacala EEB

The Task II budget provides support for salaries and benefits for up to 39.5 scientists that are Princeton University employees but work at GFDL, providing specialized scientific support for CICS related projects. Of these scientists, five to six will be at the senior rank. We also anticipate that some will be filled through visiting scholar positions. Travel support is provided for attending conferences and meetings and for relocation costs for new hires. Support for supplies, photocopying, software license agreements, and publications are also included.

The Task II budget also provides funding to support up to 15 graduate students per year to enhance the Princeton-GFDL collaboration through Ph.D. research which is relevant to the CICS themes.

Minimal costs for travel to workshops, supplies, and photocopying are budgeted.

Finally, Task II provides ongoing funding and projected new funding of subcontracts required to carry out the proposed research themes of CICS.

Indirect costs for Task II are at a reduced rate of 30% (Princeton's full indirect cost rate is 58%). Tuition is cost-shared with Princeton University and is exempt from indirect costs.

3. Task III: Individual Projects

Task III funding, which is for Individual Projects, is divided into two parts. One is entirely PI driven, with PI's responding to announcements of opportunity by NOAA; and the other is supported using funds from GFDL. The GFDL funds are further subdivided into core projects which are funded in response to proposals to GFDL in areas of specific need, and separate funds for which internal proposals are solicited and the funding determined by the CICS Executive Committee based on relevance to GFDL's mission and quality of the science.

Projects under this task make up the bulk of individual and collaborative PI research at Princeton that is supported by grants from NOAA and is aligned with the themes of CICS. It is comprised of currently funded research projects as well as new ones that strengthen the Institute's research agenda in line with the themes. Funding for new projects is normally obtained by submitting proposals for consideration to various NOAA funding bodies, subjected to a formal review process and, if successful, funded at a negotiated level. While projects listed under this task may or may not include collaboration of NOAA/GFDL scientists, they will all address research goals mutual to NOAA and Princeton. CICS facilitates the exchange of ideas between Princeton University scientists and those from NOAA.

PEI is central to the interdepartmental PI driven research projects within the CICS, through the PCC. Faculty members currently affiliated with the PCC include:

- Lars Hedin EEB/PEI
- Peter Jaffe CEE
- Simon Levin EEB
- Denise Mauzerall WWS
- François Morel GEO/PEI
- Michael Oppenheimer WWS/GEO/PEI
- Stephen Pacala EEB
- Ignacio Rodríguez-Iturbe CEE/PEI
- Jorge Sarmiento AOS/GEO
- Daniel Sigman GEO
- Eric Wood CEE

During the past year, there were four NOAA research grants other than from GFDL:

CO ₂ /CLIVAR Repeat Hydrography Program CO ₂ Synthesis Science Team	<i>Robert Key</i>	\$141,790
Atmosphere and Coastal Ocean CO ₂ Measurement Platform-SABSOON	<i>Colm Sweeney</i>	\$9,874
Ocean and Atmospheric Inverse Modeling for Global Carbon Flux Determinations	<i>Jorge Sarmiento</i>	\$155,200
Land Surface Predictability Studies at GFDL	<i>Eric Wood</i>	\$84,404

Institute resources that are reserved for new opportunities or bright ideas

In FY 06, the available Task III funding for new opportunities or bright ideas was \$507,453, of which \$306,804 has already been committed, with the remainder being set aside for new initiatives. This constitutes 38.4% of the Task III budget.

With regard to the Task II budget, most of the post-doc appointments are two years, and most of the graduate students are supported for 4 years, at which point the funds become available for new projects associated with the appointment of new post-docs and students.

C. Human Resources

CICS has no absolute employees, but rather Princeton University employees supported by CICS funding. Until this year, July 1, 2005 – June 30, 2006, all support of CICS funded Princeton personnel was for graduate students, researchers (postdoctoral fellows, research staff, research scholars, visitors, and faculty) and subcontracts to other Universities for related research. In FY06 CICS is also supporting a half-time administrative assistant and approximately 5% of the AOS Program Manager. Of the 63 individuals *supported* during last year, July 1, 2004 – June 30, 2005, the demographic structure is as follows:

RANK	Total	Male	Female	Caucasian	Asian	Other
Graduate Students	13	8	5	6	7	0
Research Assoc. (postdocs)	20	16	4	13	7	0
Research Staff	14	11	3	10	4	0
Research Scholars	5	4	1	5	0	0
Profess. Technical Staff	3	2	1	1	2	0
Visiting Research Staff	1	1	0	0	1	0
Princeton Faculty	3	3	0	1	0	2
Other Faculty	3	3	0	3	0	0
Middle School Teacher	1	1	0	1	0	0
Totals	63	49	14	40	21	2

The demographic distribution is particularly weak in senior females, an issue that CICS hopes to address in the future by recruiting more women faculty members at Princeton University who would be interested in participating in CICS research activities, and by attempting to broaden our hiring practices.

D. Financial health of the Institute

The financial management of CICS is under the overall supervision of the Director, with the Task I

and Task II budgets being administered by the AOS program and the Task III budget being administered by PIE. CICS funds are all at Princeton University; they have all been allocated, and expenditures of the remaining funds are proceeding on schedule. There are no imbalances or needed adjustments. The panel reviewed three separate budget summaries. The first of these separates the budget by Task, the second by Research Theme, and the third by NOAA funding source.

E. Issues in interacting with NOAA that require attention

The interaction between CICS and GFDL is extremely close and has been highly productive. However, interactions with the rest of NOAA have been limited. Examination of the table of NOAA funding sources by year reveals that during FY05, 69.5% of the Task III budget came from GFDL. There were four grants from the CPO, with Wood and Russell being PI's on two of them and Key on the remaining two; and one grant from the CMDL component of ESRL in support of Sarmiento's research on carbon flux determinations. The Task II budget is even more dependent on GFDL (76.8%), with three grants from CPO (PI's Held, Ramaswamy, and Hallberg).

CICS clearly would benefit by broadening its support base within NOAA. Specific considerations from the Review Committee include the following:

Recommendations: Growth areas within NOAA which might provide additional support that would enable CICS to contribute more effectively to meeting NOAA's mission include: [1] growth in the area of ecosystem-based forecasting. With the development of the Earth System Model at GFDL, the great strengths of Princeton in terrestrial and marine biogeochemistry and ecology, and the addition of a coastal modeling component, CICS is in a strong position to contribute in this area. CICS should work with NOS and NMFS to secure funding for a Fisheries Workshop.

Recommendations: CICS has a deep and abiding interest and broad range of talent in the area of paleoclimate, with strong complementary interests at GFDL. Princeton finds this as a critical factor in testing the validity of existing climate models and gaining confidence in them. Yet funding for paleoclimate research has become difficult to obtain. CICS will need to commit resource to support a person working at GFDL on developing a paleoclimate modeling capability for this area of research to be advanced.

F. Issues in interacting with the University that require attention

The ties of GFDL with Princeton University through the AOS Program have had a long and highly successful history. Until recently, the cooperative activities involved primarily the education of post-doctoral and graduate students who participated in research at GFDL. With the founding of CICS, a new element has been added to the GFDL/Princeton interaction involving direct research ties with Princeton University faculty through the Task III component of CICS. This represents both an opportunity, with Princeton faculty have becoming much more directly involved in helping GFDL to achieve its goals than was the case before; but also a challenge, in figuring out how to do an even better job of drawing on the outstanding range of talents available at Princeton University. The Review Committee has provides some recommendations some issues:

1. The close ties between GFDL and Princeton University on the development and implementation of biogeochemical models of the land and ocean requires a much closer coordination of research activities than had been before necessary. Given limited available resources, CICS and GFDL

should work together to identify additional funding to foster enhanced coordination. A particularly important factor in the interaction between GFDL and Princeton University is the recent formation of the Integrated CICS Land Model Development Team, the success of which is critical to the development of GFDL's Earth System Model. This team involves a disparate group of highly independent faculty. How this team maintains its focus and continues to work together as a team will be critical to achieve the stated goals.

Recommendation: CICS/GFDL should consider growth areas of interaction. Areas for future CICS contributions may include ecosystem management and ecobasin prediction. Linking climate to stewardship might be another area for growth. Ocean observing systems and Norma Leonard's gliders might be another area for greater campus collaboration. This could be enhanced through inviting department faculty involvement as Fellows. They might add further value to campus colleagues by seeking out Research Experience for Undergraduates (REU) and Integrated Graduate Education in Research Traineeship (IGERT) grants.

2. The vision of CICS includes a strong component regarding the "co-evolution of society and the environment" and the integration of technological, economical, social, and ethical dimensions into its research. Princeton University has great strengths in these areas that CICS has only begun to draw. Given the resident expertise on the Princeton Campus, there is a high potential for payoffs through leveraged investments by CICS in the form of graduate student and postdoc support.

Recommendation: CICS have made only modest progress on human dimensions, but they should be commended for their collaborations through the Woodrow Wilson School. There remains significant potential in this fertile area for adding context to NOAA findings that can empower decision makers.

V. EDUCATION/OUTREACH

A. Ongoing educational activities/opportunities (K-12, undergraduate and graduate students)

The primary thrust of CICS's educational contributions is the graduate program in Atmospheric and Oceanic Sciences. Since 1972 the program has produced 80 Ph.D. graduates who have gone on to a wide range of leadership positions in academia, government laboratories, and industry. The program has three graduates on the faculty at Texas A&M, and two each on the faculties of the University of Chicago, the University of Maryland, Penn State, UCLA and the University of Washington, with many more at major universities around the world. Three are on the staff at NCAR, GFDL, and NASA labs, and others can be found at ONR and NOAA as well as foreign institutions.

The program offers a range of courses including, Atmospheric Physics and Radiation, Convection, Introductory and Advanced Physical Oceanography, Geophysical Fluid Dynamics, Numerical Modeling of Atmospheres and Oceans, two semesters of Geophysical Fluid Dynamics, and a course in the phenomenology of Weather and Climate. A number of these courses draw students from other departments at Princeton (including Applied Mathematics, Mechanical and Aerospace Engineering, and Astrophysics), Princeton undergraduates, and from Rutgers University. As of Fall 2005, the program has 9 graduate students. CICS-affiliated Princeton faculty also teach a range of undergraduate courses including introductory courses in oceanography and atmospheric science and junior-level courses in global change and paleoclimate. Princeton has a strong tradition of independent work, and CICS scientists frequently advise junior projects and senior theses.

B. Current and planned outreach efforts

In support of CICS's objective to equip the next generations to respond to the increasing complexity of understanding and predicting climate and weather, CICS's outreach efforts to date have been based primarily on the "teach to teacher" model. Through workshops and a summer class for teachers, CICS should continue to leverage limited resources to have the greatest impact, reaching 25-30 students for every teacher participant.

VI. SUMMARY AND RECOMMENDATIONS

In summary, after an extensive and pleasurable review of the research, management, education, and outreach programs of the Cooperative Institute for Climate Science at the Princeton University conducted on January 18-19, 2006 in Princeton University, the committee found strengths and constructive criticisms of the existing CICS program that should be considered. A summary of the strengths of the CICS program include: [1] Dr. Jorge Sarmiento has done an incredible job without salary support as CICS Director; [2] outstanding science is being performed by highly talented scientists and students; [3] excellent collaborations exist between Princeton and the NOAA Geophysical Fluid Dynamics Laboratory (NOAA/GFDL); [4] the impressive ability to perform joint biogeochemical modeling is rivaling major modeling programs such as the Hadley Center for climate modeling; [5] students and postdoctoral scientists are in a vibrant learning environment and are very proud and happy of being at both Princeton and NOAA; [6] The GFDL based modeling in ocean and atmospheric sciences provides one of the best postdoctoral and graduate student training with the Princeton AOS division; After an objective review of the CICS program the external visiting committee is able to identify recommendations that address the weaknesses discerning the CICS Program and suggestions if Princeton University wishes the program to naturally expand in areas for a greater scientific impact in environmental research as an asset to NOAA's mission. These recommendations and suggestions are:

[1] Providing the director, Princeton Professor Sarmiento, increased support to better focus and lead CICS activities;

[2] CICS support is too strongly tied to the one source of NOAA funding through GFDL, thus, CICS should branch out to other NOAA, other federal agencies, or private foundations;

[3] Not enough support is contributed by Princeton University in the form of a main campus presence or program recognition, thus, the communication between the Forrester and Main Campus could be mitigated by small actions, such as more main campus parking spaces, to a large action, such as a dedicated main campus CICS building;

[4] CICS lacks critical mass in paleoclimate analysis and modeling to be a main theme in their mission statement, thus, CICS should bolster this activity or mitigate it from its mission statement;

[5] CICS lacks the funding support and critical mass in integrating social/physical science to address policy decision making, thus, the collaborations with the Woodrow Wilson School should be embellished, encouraged, and enhanced; and lastly

[6] Princeton University should determine whether it wishes to aggressively advance CICS as a mechanism for wider collaboration with more elements of NOAA and the nation, or continue to focus and utilize CICS as an effective joint venture with NOAA/GFDL.

Appendix A. Review Panel

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Dr. Wade McGillis is currently Doherty Scientist at the Lamont-Doherty Earth Observatory and Associate Professor of Earth and Environmental Engineering at Columbia University. His research focuses on the air-water surface exchange of carbon dioxide, heat, momentum and other climate, weather, and containment relevant compounds. Additional research interests include understanding processes controlling ocean, coastal, and river carbon dioxide transport, as well as interfacial hydrodynamics and boundary layer turbulence. Dr. McGillis was previously an Associate Scientist in the Applied Ocean Physics and Engineering Department at Woods Hole Oceanographic Institution. He holds a B.S. in mechanical engineering from Northeastern University, and an M.S. and Ph.D. in mechanical engineering from the University of California at Berkeley. Dr. McGillis is currently Chair of the United States Surface Ocean Lower Atmospheric Study, a member of the World Climate Research Program – Working Group on Fluxes, and Associate Editor of the Journal of Geophysical Research.

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Dr. Phillip Arkin is Deputy Director and Senior Research Scientist at the Earth System Science Interdisciplinary Center (ESSIC) of the University of Maryland. He helps to administer ESSIC and conducts research into the observation and analysis of precipitation and other aspects of the hydrological cycle of the global climate system. Until January 2002, he served as Program Manager for Climate Dynamics and Experimental Prediction in the Office of Global Programs at NOAA, where he managed the Applied Research Centers that provide the research and development that enable NOAA to provide better climate forecasts. From 1998-2000, he served as the Deputy Director of the International Research Institute for Climate Prediction (IRI) at Columbia University. He spent 25 years working at NOAA as a research scientist and administrator in various parts of the climate community, including the Climate Prediction Center, the Office of Global Programs and the National Centers for Environmental Prediction. His B.S. in mathematics and M.S. and Ph.D. in meteorology are from the University of Maryland.

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Dr. Fu received her bachelor's degree in geophysics in 1984 and a Ph.D. in atmospheric sciences from Columbia University in 1991, after which she worked as a post-doctoral research associate at the Department of Atmospheric Sciences at the University of California, Los Angeles, and as a visiting scientist at the Geophysical Fluid Dynamic Laboratory, Princeton University. She was previously a faculty member in the Department of Atmospheric Sciences, University of Arizona, and presently is a faculty member at the School of Earth and Atmospheric Sciences, Georgia Institute of Technology. Dr. Fu has carried out research in diagnostic studies of the dynamic and physical processes of the atmosphere hydrological and energy cycle, land-atmosphere and ocean-atmosphere interactions in tropics and applications of satellite remote sensing observations. She has served on national and international panels and programs including the review panels for the NASA Carbon Cycle Science program, the NASA ESE New Investigator Program, and the International CLIVAR/VAMOS.

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Dr. Webb received an A.B. in earth sciences from Dartmouth College in 1981, and a Ph.D. (1990) in geological sciences from Brown University. He worked as a post-doctoral research associate at NASA-GISS before taking a position as a physical scientist in the NOAA NGDC Paleoclimatology Program. Dr. Webb has been working at the NOAA Climate Diagnostics Center since 1999 and is now the interim lead for Climate Diagnostics within the Physical Science Division of NOAA Earth Systems Laboratory. His research includes reconstructing past climate from tree rings and other paleoenvironmental proxies, using global climate models to investigate the mechanisms of the past climate variability and change, and improving the use and usability of climate products and services to provide information and decision support tools for proactive planning, impact mitigation and improved responses.

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Paul Sperry is Associate Director for Science at the Cooperative Institute for Research in Environmental Sciences (CIRES) at the University of Colorado at Boulder. He was Associate Director of the Atmospheric Chemistry Division at the National Center for Atmospheric Research from 1988 to 1998, where he held the position of Associate Scientist from 1978 to 1988. His research experience includes atmospheric chemistry studies in the laboratory and field using towers, aircraft and high-altitude balloons in the study of stratospheric halides and ozone degradation, acid rain, Arctic haze, tunable diode laser development, and the measurement of various photochemical reaction rates. His recent science management efforts include establishing and conducting the new CIRES Innovative Research Program, writing a new CIRES strategic plan, developing CIRES' new Integrated Instrument Development Facility, reviewing the CIRES "Career Track" program, and establishing CIRES Computing Facility budgets and policies. Mr. Sperry holds a B.A. in chemistry from Drake University and an M.S. in systems management from Denver University.