



## Comments on Catalyzing U.S. World Climate Research Programme (WCRP) Activities

Climate Research Committee, Board on Atmospheric Sciences and Climate, Commission on Geosciences, Environment, and Resources, National Research Council

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This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

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Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by Richard M. Goody, Harvard University, appointed by the NRC's Report Review Committee, who was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.



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## SUMMARY

The purpose of this letter report is to state the findings and recommendations of the Climate Research Committee's (CRC) brief review of the U.S. contributions to the World Climate Research Programme (WCRP). The primary objectives of the review were to: (1) assess the coordination (national–international and project-to-project) of the U.S. scientific contributions to the WCRP; (2) identify potential science gaps and/or redundancies in the U.S. contributions to the WCRP, and; (3) identify existing or emerging issues and needs that might require more in-depth attention. Due to the limited time available for this review, the CRC focused on the first of these objectives. This review was requested by the U.S. Global Change Research Program (USGCRP), and was informed, in part, by a set of briefings to the CRC at its meeting on September 8, 2000. In addition to these briefings, the CRC drew upon both its own expertise and the extensive body of NRC work on this topic, including the prior work of the CRC (e.g., NRC, 1992), Tropical Oceans–Global Atmosphere (TOGA) Panel (e.g., NRC, 1996), Global Ocean–Atmosphere–Land System (GOALS) Panel (e.g., NRC, 1998a), Global Energy and Water Cycle Experiment (GEWEX) Panel (NRC, 1998b, NRC 1998c, NRC 1999a), Board on Atmospheric Sciences and Climate (BASC) (NRC, 1998d), and Ocean Studies Board (NRC, 1997). Although the set of briefings to the CRC was somewhat limited and exploratory in nature, the committee nonetheless believes that it has developed a good sense of important and emerging issues and has developed some recommendations that the committee believes require immediate agency attention.

The committee's findings and recommendations are summarized as follows:

1. The WCRP activities are scientifically strong, with broad participation by U.S. scientists in all phases of the research.
2. The principle of inter-project coordination should be based on the needs determined by the physical phenomenon being investigated. Joint research efforts should be organized to address specific scientific questions or phenomenological features that span two or more WCRP project communities.
3. There are disparities in the nature of the support that relevant U.S. research agencies give to the different WCRP elements; similarly, the coordination among the agencies varies considerably from one WCRP element to the next.
4. There is currently no centralized “focal point” for coordinating U.S. efforts associated with the Global Energy and Water Cycle Experiment (GEWEX), the USGCRP Water Cycle initiative, or the Arctic Climate System Study (ACSYS)/Climate and Cryosphere (CLIC), and Stratospheric Processes and their Role in Climate (SPARC) projects. The committee recommends that the agencies establish an appropriate national “focal point” for these activities. Each focal point should clearly identify the major areas of intersection of its project with the other U.S. WCRP projects. It also should serve as a point of contact and as a coordinating mechanism for domestic and international scientific implementation and cooperation both within the project and with other related projects. If the TOGA model were to be followed, each focal point would consist of a project office (or project coordinator) and a scientific advisory group (NRC, 1996), each of which could be scaled to the size and scope of the project. In the case of GEWEX, the committee reiterates a previous NRC recommendation that a U.S. project office be established (NRC, 1999a), which could be shared with a broader U.S. Water Cycle office. For smaller projects (e.g., SPARC and ACSYS/CLIC), project coordination could be carried out by other mechanisms, such as by a single individual and/or by co-locating the coordination foci with other established project offices.

5. There should be a mechanism agreed to by the relevant agencies for establishing the nation's research priorities regarding the WCRP, particularly for those areas in which a large-scale, concerted effort is required and where the issue lies outside the boundaries of primary responsibility of any individual agency (NRC, 1999b). Two such issues, upon which the CRC places high priority, are the attribution of the causes of observed climate change and the projection of future climate change. Both of these require large computational and human resources and depend crucially on a high-quality, long-term observational system (NRC, 1998e). The ability to take action on these priorities depends upon the ability of the agencies to collectively direct resources toward them (NRC, 2001). However, as noted in *The Science of Regional and Global Change: Putting Knowledge to Work* (NRC, 2001, hereafter *The Science of Regional and Global Change*), "The current situation in the federal government does not sufficiently promote delivery of resources to key research, observational, and technological endeavors that either cross or transcend formal agency responsibilities."
6. Adequate and timely funding of the projects is essential to ensure the success of the WCRP. This requires that the members of the Subcommittee on Global Change Research, and other leaders of the key agencies, be aware of these projects and the interagency priorities (see above) when making commitments for their respective contribution. Also, the individual agencies involved in the projects should ensure that the Office of Management and Budget and the appropriate congressional committees are fully knowledgeable of the projects and their required funding.

## BACKGROUND

Because of the global nature of climate, there is a fundamental need for international coordination and cooperation to observe the climate system and carry out the comprehensive research program required to improve the description and understanding of climate, climate variability, and climate change, and to determine its predictability.

Motivated by the emergence of climate science as a major area of research, and the need to address in a global context the socio-economic aspects of climate variability and change, the World Climate Programme (WCP) was initiated in 1979. The major sponsoring organizations of the WCP at the international level are the World Meteorological Organization (WMO), the United Nations Environment Programme (UNEP), the Intergovernmental Oceanographic Commission of UNESCO and the International Council for Science (ICSU). The World Climate Research Programme (WCRP), which is one of the components of the WCP, was established in 1980 under the joint sponsorship of ICSU and WMO, and has also more recently been sponsored by the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO). The WCRP began as a component of the WCP to promote international coordination of those aspects of climate research where such coordination is needed or desirable. The WCRP describes its objectives as follows:

WCRP studies are specifically directed to provide scientifically founded quantitative answers to the questions being raised on climate and the range of natural climate variability, as well as to establish the basis for predictions of global and regional climatic variations and of changes in the frequency and severity of extreme events.

During its early stages the WCRP adopted the concept of three “research streams” focused on short, intermediate, and long-term climate processes (WCRP, 1984). The first stream focused on studies of processes that are strongly influenced by transient weather phenomena, such as radiation and cloud interactions and land surface hydrology. The second stream, addressing intermediate seasonal-to-interannual variations, was in essence the Tropical Ocean-Global Atmosphere (TOGA) project. In the third stream the World Ocean Circulation Experiment (WOCE) was to be the first step in a comprehensive study of the dynamics of long-term climate changes, which involve the global ocean circulation in a fundamental way.

The scientific and organizational challenge of TOGA, which was established in 1985 and completed in 1994, was to bring together a community of meteorologists and oceanographers with different perspectives in an integrated study of the coupled ocean/atmosphere system. In terms of the full spectrum of climate system interactions, the TOGA project had limited objectives. For example, it did not address global atmospheric–surface (ocean and land) interactions—issues now addressed by GEWEX and CLIVAR—and was focused primarily on seasonal-to-interannual time scales.

The NRC’s CRC was designated as the U.S. National Committee for the WCRP in 1981. TOGA was the first WCRP project for which CRC review and oversight was requested. TOGA is generally considered to be a very successful program, and some of the lessons learned, including those on both the national and international fronts, were documented in *A Decade of International Climate Research: The First Ten Years of the World Climate Research Program* (NRC, 1992) and *Learning to Predict the Climate Variations Associated with El Niño and the Southern Oscillation* (NRC, 1996). The following are some of the committee’s interpretations of the relevant findings of these reports:

- Progress is most rapid when scientists engage models in an interactive confrontation with observations at an early stage (preferably the planning stage) in major climate research programs. This confrontation should involve assessment of model veracity as well as model-based diagnoses of the observations, which, in turn, suggest additional diagnoses of the observations.
- A tripartite management structure on the national scene was an effective way of managing the program. This structure consisted of a TOGA Program Office, an advisory mechanism (in this case through the NRC TOGA Advisory Panel), and a funding mechanism through the USGCRP. This was mirrored on the international scene by an International TOGA Program Office, the TOGA Scientific Steering Group, and the Intergovernmental TOGA Board—all part of the WCRP (NRC, 1996).
- Part of the reason for TOGA's success was the focus on a single phenomenon: El Niño/Southern Oscillation (ENSO). In the words of *Global Environmental Change: Research Pathways for the Next Decade* (NRC, 1999b), "Scientists from different fields work together most productively and smoothly when the problem demands it—and global change demands it."
- The establishment and sustenance of a global program and perhaps observing systems require international coordination and a national point of focus able to respond to the demands of international coordination.

It should also be noted that in the CRC's previous review of the WCRP and its programs (NRC, 1992), the committee pointed out that one of the WCRP's shortcomings was the lack of coordination among the various projects. The CRC therefore accepts as an additional lesson:

- The projects of the WCRP should be coordinated at both the national and international levels.

During the past decade, the number and complexity of WCRP projects have increased as the scope of WCRP research activities have become more interdisciplinary and comprehensive. Consequently, issues of program size, scope, organization, and coordination as they relate to U.S. participation in the WCRP have arisen that were not present in the early years when WCRP consisted of a single program element.

Based in part on discussions at a meeting of the CRC in March 2000, it was determined that a review of U.S. WCRP activities was appropriate. *This initial review is relatively limited and exploratory in nature.* The primary objectives of the review are to: (1) exchange information and views between the Committee and national WCRP project leaders in order to reach a better understanding of how individual WCRP projects are being coordinated (national–international and project-to-project); (2) identify existing or emerging issues and needs that might require more in-depth attention; and (3) develop recommendations, if appropriate.

The briefings that informed this review were held on September 8, 2000. Presentations were made by U.S. participants in both national and international WCRP activities. The CLIVAR project was represented by the U.S. CLIVAR project director and a co-chairman of the U.S. CLIVAR Scientific Steering Committee (SSC), as well as representatives of the international CLIVAR SSCs. Briefings on the remaining WCRP activities were presented by U.S. participants in the international components of the WCRP projects.

## WCRP AT THE INTERNATIONAL LEVEL

### OVERVIEW

To address its objectives (see the next section), the WCRP has organized a number of international research and observational projects on selected aspects of the atmosphere, ocean, sea ice, and land surface as interacting components of the physical climate system. At present the WCRP has five active research projects, in addition to a broad program in support of numerical modeling. These projects are GEWEX, CLIVAR, WOCE, ACSYS/CLIC, and SPARC. Each of these WCRP projects has an international scientific steering group (SSG) and an international project office located in one of the participating nations. Each SSG has prepared or is in the process of preparing (in the case of CLIC) a science and implementation plan. There is major U.S. participation in international SSG activities, the extent of which varies from project to project.

The international research activities of each project are described in their respective science and implementation plans. Approval of these plans and responsibility for overall coordination of the suite of projects rest with the WCRP Joint Scientific Committee (JSC). The JSC provides scientific review and evaluation of the WCRP to ensure a well-coordinated program. The JSC is supported by the WCRP Joint Planning Staff (JPS) located in Geneva, Switzerland. The United States has and continues to be strongly represented on the JSC. The recently retired JSC chairman (Larry Gates) was from the United States and served for six years.

One of the objectives of the WCRP is to help provide the international framework for scientific cooperation in the study of global change. It is joined collaboratively in this effort with a number of other related international programs, e.g., International Geosphere-Biosphere Program (IGBP), Global Climate Observing System (GCOS), International Human Dimensions Program (IHDP), and elements of the WCP. The JSC and JPS also maintain coordination with the Intergovernmental Panel on Climate Change (IPCC) and the Inter-Agency Committee on the Climate Agenda (IACCA).

### CURRENT WCRP PROJECTS

Each of the WCRP projects brings together a community of scientific expertise that is focused on the central objectives of the project. However, global climate system interactions are fundamentally intertwined and cannot be easily partitioned into such separate components. There are major intersections between the projects in terms of scientific questions and data needs. For example, the cryosphere is a sub-component of the global hydrologic cycle, and consequently both GEWEX and CLIC have many common scientific questions and objectives relating to cryosphere processes in the global and regional energy and water cycles, particularly as they relate to land surface hydrology. However, in addressing the scientific issues, the differences in the major thrusts and the expertise of the two scientific communities will likely lead to different emphases, e.g., time scales and approaches.

### GEWEX

GEWEX was established in 1988 and has no termination date<sup>1</sup>. It was conceived as a comprehensive research program to investigate the climate–weather connection. It is a mature project whose central objectives are to observe and model the hydrologic cycle and energy fluxes in the atmosphere, at the land surface, and in the upper oceans. Among its ultimate goals is to improve predictions of global and regional climate change. To this end, GEWEX nurtured, from its very beginning, a close working relationship with (1) the numerical weather prediction community (especially

<sup>1</sup> The CRC has not considered. Copyright © National Academy of Sciences. All rights reserved. GEWEX and SPARC.



the European Center for Medium-Range Weather Forecasting and the U.S. National Centers for Environmental Prediction), and (2) space agencies that were interested in developing global observing capabilities beyond that of the operational space-based observing system inherited from the First Global Atmospheric Research Program Global Experiment. Regarding the latter item, GEWEX has been instrumental in shaping the current generation of climate-observing satellite programs, notably NASA's Tropical Rainfall Measuring Mission, EOS Aqua, and Cloudsat missions; the European Space Agency's Earth Observation Explorer Program; and Japan's future Global Climate Observing Mission (GCOM).

GEWEX serves as the umbrella project for a variety of subprojects focused on data set development and research activities required to address the broad, multidisciplinary objectives of the project. GEWEX has made major contributions to the understanding of the energy and water cycles through the regional and global data sets that have been produced under its auspices, including those of precipitation, clouds, water vapor, radiation, aerosols, and land surface characteristics and hydrology (see, e.g., NRC, 1998c, 1999c). It has also contributed quite substantially to the understanding of processes and interactions of the energy and water cycles at local to global scales, and to their representation in models at a wide range of time and space scales<sup>2</sup>. The International GEWEX Project Office is located in Washington, D.C., and has been supported by NASA and NOAA.

### WOCE

WOCE was initiated through the efforts of the Scientific Committee on Oceanic Research (SCOR)–Intergovernmental Oceanographic Commission (IOC) Committee for Climate Change and the Ocean (CCCO) and the WCRP JSC. Its initial planning was completed in the 1980s with the release of a science plan (WCRP, 1986) and a two-volume implementation plan (WCRP, 1988). WOCE was designed to produce a description of the large-scale ocean circulation and its transports of heat, mass, and freshwater; to understand the climatic state of the ocean; and to understand the relevant processes that set that state. This knowledge is helping to improve coupled models for climate diagnosis and prediction. Global in situ coverage at the space and time scales relevant for climate with complementary satellite observations was achieved in WOCE. The field phase of WOCE extended from 1990 to 1997. The project is now in its analysis, interpretation, modeling, and synthesis (AIMS) research phase which will continue to 2002. Ocean state estimation is one of the central foci of the AIMS phase. At the beginning of WOCE there was little confidence in the prospect of bringing models and data together in a full ocean state estimation. It has now been shown that such a synthesis is technically feasible (WOCE, 1997).

The WOCE bibliography, maintained by the WOCE International Project Office, already numbers more than a thousand articles, many contributing significantly to understanding regional as well as global oceanography. The results of WOCE are accretionary. Taken as a whole, WOCE is providing numerous significant advances for large-scale oceanography and a firm basis for progress in studying the coupled ocean–atmosphere climate system. The international WOCE and CLIVAR Projects now share the same Project Office in Southampton, U.K.

### CLIVAR

The international CLIVAR Project was established in 1995 as a 15-year WCRP activity<sup>3</sup>. It is focused on determining the causes and predictability of climate variations on seasonal-to-decadal time-scales, including those climate changes due to human activity. CLIVAR is fostering the development

<sup>2</sup> Also see the GEWEX Science Plan (WCRP, 1990).

<sup>3</sup> The U.S. CLIVAR Program Copyright © National Academy of Sciences. All rights reserved.

of coupled models of the climate system and the collection of atmospheric and oceanic observational data on the longer time-scales needed for the development and validation of comprehensive climate system models. The approach proposed by CLIVAR is the most comprehensive and ambitious of the present WCRP projects. As a result of its breadth, CLIVAR significantly interfaces with all of the other WCRP projects; its success will depend in part on input from the other WCRP projects as well as from other international programs<sup>4</sup>.

### SPARC

SPARC was established in 1992 and has no termination date. The objectives of SPARC are to relate chemical and dynamical processes in the stratosphere—including those involving ozone, aerosols, and water vapor—to the tropospheric and surface climate, and to coordinate the development and improvement of global numerical models of the stratosphere. Unlike other WCRP projects or, e.g., IGAC (International Global Atmospheric Chemistry project, a lower atmosphere SPARC-like project within IGBP), SPARC's emphasis is oriented toward theory and models rather than on coordination of field programs. Among the products of SPARC are two significant reports on stratospheric trends of ozone (WMO, 1998) and temperature (Ramaswamy et al., 2001). Another soon-to-appear report addresses upper tropospheric/lower stratospheric water vapor observations, climatology, and variability—information vital for a number of purposes, including understanding of the water vapor feedback. Among several other sub-projects, an intercomparison of troposphere–stratosphere chemical–climate models is currently underway (Fairlie et al., 1998) that will help elucidate the relative merits of various approaches for codifying upper level processes. The International SPARC Project Office is currently located in Paris. Its current Director, Marie-Lise Chanin, is also the Co-Chair of the SPARC SSG<sup>5</sup>.

### ACSYS/ CLIC

Established in 1993, ACSYS is focused on determining the relationship of the oceanography and hydrology of the Arctic Basins to the surrounding continents and adjacent oceans, with emphasis on observing and modeling sea ice. ACSYS will phase out as the more comprehensive Climate and Cryospheric (CLIC) project develops<sup>6</sup>. CLIC was endorsed by the JSC in March 2000, and the coordinating structure and implementation aspects of the project are currently under development. Its basic objective is to integrate existing global cryospheric projects (bipolar) within a global research structure, and in addition address current gaps in global cryospheric research. The International Project Office has been established in Tromso, Norway.

### Modeling Working Groups

Jointly with the WMO Commission for Atmospheric Sciences, the WCRP supports the Working Group on Numerical Experimentation (WGNE). The WCRP also supports the Working Group on Coupled Modeling (WGCM) jointly with CLIVAR. This group focuses on the use of coupled atmosphere–ocean models for climate prediction in support of CLIVAR, and ultimately on the development of comprehensive climate-system models.

<sup>4</sup> See the international CLIVAR Science Plan (WCRP, 1995) and the Implementation Plan (WCRP, 1998a).

<sup>5</sup> See the international SPARC Science Plan (WCRP, 1993) and Implementation Plan (WCRP, 1998b).

<sup>6</sup> See the ACSYS Implementation Plan (WCRP, 1994) and CLIC Science and Implementation Plan (WCRP, 2001).

## COMMENTS ON U.S. PARTICIPATION IN WCRP

The primary focus of this review is to briefly assess the efficacy of the U.S. national components of the WCRP projects and their links with the international programs. Based upon the presentations to the CRC at its recent meeting and on the resident expertise of the committee, the CRC concludes that the WCRP is a successful program and is making substantial progress toward its stated objectives. The committee commends the contributions of the U.S. science community for its invaluable contributions to the WCRP. Without these contributions in the form of observations, research, and scientific wisdom, many of the major advances that have occurred via the WCRP would not have been possible, including those in the areas of climate variability and change, atmospheric chemistry, ocean dynamics, and solid and liquid fresh water processes. Currently, the organization of U.S. contributions to the WCRP varies in fundamental ways from project to project.

When TOGA was established as the first WCRP project in 1985, the United States established a national structure for scientific guidance and coordination, which mimicked that of the international project—namely a national scientific steering committee (SSC) that prepared national science and implementation plans, and a national TOGA Project Office that served as the focal point for U.S. scientific and funding-agency coordination. This model has now been adopted for U.S. CLIVAR, and is supported through the leadership of several agencies including NOAA, NASA, and NSF. This model has also been adopted by U.S. WOCE, and the U.S. WOCE Project Office, located in College Station, Texas, has played a vital role in coordinating the large U.S. contributions to the international WOCE arena.

Prior to the establishment of the U.S. CLIVAR Project Office, briefings to the CRC in 1999 indicated that coordination of CLIVAR projects within the United States, as well as coordination of U.S. CLIVAR research efforts internationally, were somewhat disarrayed. Following the establishment of the U.S. CLIVAR Project Office, reports to the CRC by a co-Chair of the U.S. CLIVAR SSC and by members of the international CLIVAR SSG indicated a marked improvement in the science coordination and direction, resulting in substantial benefit to the scientific community. The U.S. CLIVAR Project Office and the U.S. CLIVAR SSC are coordinating the activities of several scientific advisory bodies that are tasked with establishing and implementing the research around the priority foci of the U.S. CLIVAR project. These bodies include the Pacific, Atlantic, and Pan-American Implementation Panels and the Seasonal-to-Interannual Modeling and Prediction (SIMAP), U.S. PAGES/CLIVAR, and Asian-Australian Monsoon Working Groups. The U.S. CLIVAR SSC has drafted an implementation plan that was released in early 2001.

The TOGA model has not been adopted by GEWEX, ACSYS/CLIC, or SPARC. In the case of GEWEX, the U.S. has played a major role in almost all aspects of the international project, e.g. project development and scientific leadership of a host of individual elements of the project. This wide variety of GEWEX activities has been supported by U.S. agencies, notably NOAA and NASA. The United States has played a leadership role in GEWEX, in part through the development of several data sets, alluded to in the previous section, that are required to describe and diagnose the characteristics of the interlinked global energy and water cycles, e.g., International Satellite Cloud Climatology Project, Global Precipitation Climatology Project, Global Water Vapor Project, as well as several others useful for characterizing land surface and atmospheric conditions. U.S. remote sensing is expected to contribute substantially to the GEWEX Coordinated Enhanced Observing Period (CEOP), which endeavors to synthesize a period of observations of unprecedented comprehensiveness.

The United States has contributed substantially to GEWEX through the GEWEX Continental-Scale International Project (GCIP)—the first of GEWEX's several regional Continental-Scale Experiments (CSEs). GCIP is essentially a U.S. project, with its own scientific steering groups and project office in Washington, D.C. The GCIP Project Office was very effective in implementing GCIP's objectives. One

example of the success of GCIP is the benefit that U.S. meteorological modeling efforts have derived from it. GCIP facilitated the integration of process-research findings and data in operational prediction systems through cooperation with (and funding of) relevant dedicated data analysis and assimilation activities at the National Centers for Environmental Prediction (NCEP) using the mesoscale Eta model<sup>7</sup>. The GEWEX Americas Prediction Project (GAPP), which will succeed GCIP, promises to carry on the advances initiated by GCIP and to attack some of the promising areas highlighted in the NRC's review of GCIP (NRC, 1998c). To date, however, infrastructure support or a project office for GAPP have not been put in place.

Each of the GEWEX sub-projects has significantly advanced understanding in the areas that they specifically target. However, the U.S. contributions to GEWEX—which have grown enormously in the past decade—have not been fully integrated to meet the broad objectives of the international GEWEX program. These objectives include the goal of determining the hydrologic cycle and energy fluxes by means of global measurements of atmospheric and surface properties. A notable exception is the work of the Water and Energy Budget Study (WEBS), facilitated by the U.S. GCIP project office (which is being scaled back), which has been able to improve the “closure” of estimates of the coupled energy and water cycle budgets over the Mississippi River basin. However, a comprehensive U.S.-wide synthesis, let alone a global synthesis of the GEWEX data that substantially refines U.S. and global energy and water cycle budget estimates, is currently lacking. The integration of hydrologic and energy cycle data to determine the U.S. budgets is one of several areas in which a U.S. GEWEX/Water Cycle project office could substantially contribute by organizing a coherent synthesis of the individual research and data collection efforts. Such an integration effort is necessary if U.S. scientists are to make major contributions to CEOP. In addition, U.S. GEWEX activities are now set within the broader context of the U.S. Water Cycle initiative and will require strong coordination to ensure that energy cycle research is not artificially decoupled from water cycle research—a tendency that has cropped up in the past. A joint U.S. GEWEX/Water Cycle office could redress these concerns, as well as those pertaining to coordination between GEWEX and the other WCRP projects. The latter coordination depends strongly on the existence of clear “focal points” for each of the WCRP projects.

The activities of SPARC have been well received by the scientific community, and U.S. scientists have been enthusiastic participants. Two of the ten members of the SPARC SSG are from the United States, as is one of the two Co-Chairs, Marvin Geller, an effective leader for the U.S. effort. The U.S. effort, which does not have a project office, is heavily dependent on Geller, who hosts a data center and website. Both Geller and Co-Chair Chanin are planning to step down soon, and the location of the international project office is likely to change. These transitions will likely mean that the nature of the U.S. contribution to the program will change. All of SPARC's trend-assessment, data set development, and model-related activities have involved strong leadership of individual U.S. scientists. These activities are viewed by the scientific community as critical efforts that fill gaps to complement international assessments on ozone and climate. SPARC studies, like the project as a whole, are designed to focus science and funding on basic stratospheric and climatic processes, at a time when some agencies and some in the scientific community view trends as “known” or the assessment issues as “solved.” Thus, the CRC views U.S. participation in SPARC as crucial.

U.S. scientists have played a major role in the development of the international CLIC Science and Coordination Plan. For instance, Roger Barry is a Vice Co-Chair of the International CLIC SSG. The United States provides strong intellectual leadership in most facets of cryospheric/polar climate research, including seminal work on the polar annular oscillations, sea and land ice and ocean dynamics, polar cloud processes, frozen precipitation, and many other areas. It is quite logical that the United States fully capitalize on its substantial scientific investments by exerting a concerted effort with CLIC

<sup>7</sup> See NRC 1998c for further details. Copyright © National Academy of Sciences. All rights reserved. that require additional work.

to continue this progress and provide critical insight into questions including (but certainly not limited to) those related to the nature and magnitude of polar feedbacks to greenhouse gas and lower latitude forcing.

A major strength of WOCE has been the collection of many different types of complementary data and development of models and investigator expertise for almost every ocean basin. U.S. investigators have played a substantial role in most of these endeavors. The combination of satellite and in situ observations has provided a comprehensive suite of WOCE data sets, both in terms of the variables measured and the geographical coverage.

The massive scale and scope of WOCE has led to concerns about it being unfocused, unlike, for instance, the tropical Pacific experiments with the unified goal of describing and predicting El Niño. However, the central WOCE problems ultimately concern the entire global ocean and atmosphere at long time scales, and cannot be fully understood without a global perspective. In addition to global-scale issues, WOCE data sets are also being used to unravel a plethora of issues of roughly the same scope as El Niño, some of which are blossoming into larger ongoing projects. These studies address mid-latitude decadal climate phenomena such as the Pacific Decadal Oscillation, the North Atlantic Oscillation, and counterpart southern hemisphere signals for which both the real-time observing and assimilation initially put in place for WOCE is being continued. The particular scientific questions that are being answered by the global data sets per se are of the same ilk as those for each region—describing the nature and variability of global thermohaline and wind-driven circulation and their concomitant heat and property transports. These data sets have also been used in a number of WOCE regional process experiments that address specific scientific questions such as the detailed mechanisms of ventilation through subduction and convection, thermocline and abyssal mixing rates, abyssal upwelling processes, and formation of water masses such as North Atlantic Deep Water and Labrador Sea Water.

WOCE-related assimilation efforts are maturing in the United States, Europe, and Japan. Ongoing efforts in basin-wide geostrophic circulation estimation are still largely preliminary. Model resolution, spatial extent, and employed physics must further be expanded and the entire WOCE data set incorporated. Moreover, the field is rapidly migrating towards operational applications of ocean state estimation, facilitating estimates of changes in ocean circulation on seasonal to longer climate-relevant time scales, similar to re-analysis projects in the atmospheric community.

## CATALYZING PROGRESS

In order to maximize the scientific payoff from the overall WCRP, the U.S. projects need to be conducted so that the efforts of the individual projects are integrated and synthesized in a manner which ensures that the whole will be more than the simple sum of the individual projects. This requires coordination, cooperation, and integration of the observations, data set development, field programs, analysis, and other research activities (NRC, 1999b).

There should be a mechanism agreed to by the relevant agencies for establishing the nation's research priorities regarding the WCRP. In the current approach important areas may not have strong advocates in the existing agency structure, and the needed observation systems, for example, are too costly for each agency to build its own (NRC, 2001). The nation's current climate monitoring capabilities are not precise enough, do not have adequate spatial coverage, and do not monitor all of the critical variables necessary to develop a comprehensive understanding of the climate system (NRC, 1999d). As stated in *Decade-to-Century-Scale Climate Variability and Change: A Science Strategy* (NRC, 1998e), two other issues upon which the CRC places high priority are the attribution of the causes of observed climate change and the projection of future climate change. The current U.S. National Assessment and Intergovernmental Panel on Climate Change assessment processes underscore the desirability of better information in these two areas. Both of these areas require large computational and human resources and depend crucially on a high-quality, long-term observational system—attributes that are currently lacking (NRC, 1998f). To paraphrase *The Science of Regional and Global Change*, the ability to take action on these priorities, particularly those that require a concerted large-scale effort, depends on the ability of the agencies to collectively direct resources toward them (NRC, 2001). As noted in that same report, “The current situation in the federal government does not sufficiently promote delivery of resources to key research, observational, and technological endeavors that either cross or transcend formal agency responsibilities,” (NRC, 2001). These deficiencies apply not only to the nation's ability to promote progress toward the objectives of the WCRP, but also to the broader global change enterprise (NRC, 2001).

Regarding the relationship between GEWEX and CLIVAR in the United States, the CRC reiterates the conclusions of the NRC GEWEX Panel (NRC, 1998b) that the implementation of U.S. involvement in these two projects must be tightly coupled. The coordination necessary between the two programs is most appropriately centered around specific phenomena. The CRC highlights the joint GEWEX–CLIVAR North American Monsoon Experiment (NAME) as an excellent example of the type of collaborative relationship that should continue to be fostered. NAME examines the nature, forcing, predictability, and impacts of this monsoon system, and in so doing directly benefits the research objectives of both GEWEX and CLIVAR. This type of interaction helps dispel the unproductive myth that GEWEX is simply a land–atmosphere project and CLIVAR is simply an ocean–atmosphere project. Unfortunately, there is currently no U.S. GEWEX point of contact to facilitate the entrainment of GEWEX's expertise into NAME.

The CRC encourages U.S. members of the CLIC scientific community to develop a coordinated U.S. CLIC component to catalyze and integrate the diverse U.S. expertise in this area. In order to avoid overlaps and gaps, the implementation of CLIC will require close attention to the development of its many interfaces with other WCRP projects, notably GEWEX and CLIVAR. The U.S. CLIC research community should pay particular attention to commonalities with the cold season work conducted in GCIP—which is now transitioning into the GEWEX America Prediction Project—and the polar cloud working group of the GEWEX Cloud Systems Study. Abroad, linkages between CLIC and other GEWEX Continental-Scale Experiments (Mackenzie GEWEX Study (MAGS); GEWEX Asian Monsoon Experiment (GAME)/Siberia; and Baltic Sea Experiment (BALTEX)) could lead to productive collaborative work. The CLIC planning process should search out cooperative opportunities

with relevant aspects of CLIVAR such as those addressing the North Atlantic Oscillation and deep water formation (e.g., CLIVAR Atlantic Panel).

CLIVAR's connection to SPARC is also important, particularly with respect to understanding the controls on tropospheric climate. There appears to be potential predictability of climate in mid-latitudes during winter time in response to antecedent stratospheric conditions, for example in association with explosive volcanism and the annular modes of climate variability.

To achieve the WCRP's objective of understanding and predicting the full range of climate variability will require integrating what is learned from each of the program's projects. It cannot be assumed that this integration will be achieved *ex post facto* and, therefore, needs to be encouraged throughout the evolution of the projects.

A GEWEX Panel of the CRC was established in 1993, but was discontinued in 2000 in anticipation of the development of a unified water cycle initiative. This initiative has been concurrent with the formation of the NRC Committee on Hydrologic Science (COHS). In light of the major role that the United States has played in GEWEX, it might seem surprising that no national focal point comparable to that for TOGA, WOCE, and CLIVAR has been established for the project. Although establishment of a U.S. GEWEX Project Office was recommended by the NRC (NRC, 1998b, 1999a), to date this recommendation has not been acted upon by funding agencies. All agencies whose research efforts benefit directly from the data set development, process studies, and modeling tools developed through GEWEX (e.g., NOAA, NASA, NSF, and DOE) would be well-served to support such an office due to the substantial value that is added to each agency's activities through joint participation in the Project (i.e., making the whole greater than the sum of the parts). Moreover, implementation of the interagency water cycle initiative will require central coordination which could be supplied by a GEWEX/Water Cycle project office.

With no national focal point and its international project office currently located in Paris (but likely to be relocated soon), U.S. scientific activities associated with SPARC have crucially depended on strong U.S. leadership within the international SPARC SSG, notably that of its current co-chair who is from the United States. The new SSG co-chair may or may not be a U.S. scientist. Without a U.S. focal point, the link with the international project is indeed tenuous. The same can also be said for CLIC. Thus, the CRC is concerned that the U.S. scientific community and agencies not overly rely on the heretofore strong, but not guaranteed, willingness and ability of individual U.S. scientists to coordinate U.S. efforts with those of the international projects upon which much of the U.S. research is pinned.

In light of the imperatives for coordination, cooperation, and integration of the observations, data set development, field programs, analysis, and other research activities, as well as the lessons learned from TOGA, the CRC has the following recommendations for the national response to WCRP programs:

- There should be a national "focal point" for implementing each of the projects of the WCRP that are to be carried out over the next several years (see, e.g., NRC, 1996, 1998a, 1999a). Each focal point should clearly identify the major areas of intersection of its project with the other U.S. WCRP projects. It should serve as a point of contact and as a coordinating mechanism for domestic and international scientific implementation and cooperation both within the project and with other related projects. The TOGA model implies that the advice from each project's advisory group could be coordinated through the CRC, the U.S. National Committee to the WCRP.
- If the TOGA model, which the CRC views as an effective one, is to be followed, the focal point should consist of a project office (or project coordinator) and a scientific advisory group (NRC, 1996), each of which could be scaled to the size and scope of the project. For smaller projects

(e.g., SPARC and ACSYS/CLIC), project coordination could be carried out by a single individual on a part-time, but continuous basis. In addition, the project coordinators/offices of GEWEX/Water Cycle, SPARC, and ACSYS/CLIC could be co-located with the CLIVAR project office as per a previous recommendation (NRC, 1999a). There undoubtedly exist other options for establishing these critical project offices or coordination foci. Consideration should be given to cross membership, where needed, between various project or sub-project advisory groups, as has been recommended in the CLIC international planning document. The project office and advisory group for each project should monitor the interactions of modeling and observations within each program. The recommendation for project focal points made in this report is not a plea for the diversion of large amounts of money from science to bureaucracy. Rather, it is a call for wise science management based on a proven approach.

- The principle of inter-project coordination should be based in part on the needs determined by the physical phenomenon being investigated. Joint research efforts should be organized that focus on specific scientific questions or phenomenological features that span two or more WCRP project communities. As mentioned previously, a good example of this type of coordination between GEWEX and CLIVAR is the joint work on the North American Monsoon Project. Examples of other such foci spanning more than one project are North Atlantic climate variability and change (NAO and thermohaline studies via CLIVAR and CLIC), North American cold season hydrologic processes (GEWEX and CLIC), and understanding and modeling the coupling between troposphere and stratosphere (SPARC and CLIVAR). This integration needs to be encouraged throughout the evolution of the projects.
- There should be a mechanism agreed to by the relevant agencies for establishing the nation's research priorities regarding the WCRP, particularly for those areas in which a large-scale, concerted effort is required and where the issue lies outside the boundaries of primary responsibility of any individual agency (NRC, 1999b). Two such issues upon which the CRC places high priority are the attribution of the causes of observed climate change and the projection of future climate change. Both require large computational and human resources and depend crucially on a high-quality, long-term observational system (NRC, 1998e). The ability to take action on these priorities depends upon the ability of the agencies to collectively direct resources toward them (NRC, 2001). However, as noted in *The Science of Regional and Global Change*, "The current situation in the federal government does not sufficiently promote delivery of resources to key research, observational, and technological endeavors that either cross or transcend formal agency responsibilities," (NRC, 2001).
- Adequate and timely funding of the projects is essential to ensure the success of the WCRP. This requires that the members of the Subcommittee on Global Change Research, and other leaders of the key agencies, be aware of these projects and the interagency priorities (see above) when making commitments for their respective contribution. Also, the individual agencies involved in the projects should ensure that the Office of Management and Budget and the appropriate congressional committees are fully knowledgeable of the projects and their required funding.



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## ACRONYMS

ACSYS	Arctic Climate System Study
AIMS	Analysis, Interpretation, Modeling and Synthesis
BALTEX	Baltic Sea Experiment
BASC	Board on Atmospheric Sciences and Climate
CEOP	Coordinated Enhanced Observing Period
CLIC	Climate and Cryosphere
CLIVAR	Climate Variability and Predictability
COHS	Committee on Hydrologic Science
CRC	Climate Research Committee
CSE	Continental Scale Experiment
DOE	Department of Energy
ENSO	El Niño/Southern Oscillation
GAME	GEWEX Asian Monsoon Experiment
GAPP	GEWEX Americas Prediction Project
GCIIP	GEWEX Continental-Scale International Project
GCOS	Global Climate Observing System
GCSS	GEWEX Cloud System Study
GEWEX	Global Energy and Water Cycle Experiment
GOALS	Global Ocean–Atmosphere–Land System
IACCA	Inter-Agency Committee on the Climate Agenda
ICSU	International Council for Science
IGAC	International Global Atmospheric Chemistry
IGBP	International Geosphere-Biosphere Program
IHDP	International Human Dimensions Program
IOC	Intergovernmental Oceanographic Commission
IPCC	Intergovernmental Panel on Climate Change
JPS	Joint Planning Staff
JSC	Joint Scientific Committee
MAGS	Mackenzie GEWEX Study
NAME	North American Monsoon Experiment
NAO	North Atlantic Oscillation
NASA	National Aeronautics and Space Administration
NCEP	National Centers for Environmental Prediction
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
NSF	National Science Foundation
OMB	Office of Management and Budget
PAGES	Past Global Changes
SGCR	Subcommittee on Global Change Research
SIMAP	Seasonal-to-Interannual Modeling and Prediction
SPARC	Stratospheric Processes and their Role in Climate
SSC	Scientific Steering Committee
SSG	Scientific Steering Group
TOGA	Tropical Ocean and Global Atmosphere
UNEP	United Nations Environment Programme
UNSECO	United Nations Educational, Scientific and Cultural Organization

USGCRP	United States Global Change Research Program
WCP	World Climate Programme
WCRP	World Climate Research Programme
WEBS	Water and Energy Budget Study
WGCM	Working Group on Coupled Modeling
WGNE	Working Group on Numerical Experimentation
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment

## COMMITTEE AND STAFF BIOGRAPHIES

### CHAIRMAN

**Dr. Eugene M. Rasmusson** is a Research Professor Emeritus in the Department of Meteorology at the University of Maryland. In 1999 Dr. Rasmusson was awarded membership to the National Academy of Engineering. His research expertise lies broadly in general climatology with an emphasis on seasonal-to-interannual climate predictability. Dr. Rasmusson's NRC experience is wide-ranging including membership on the Board on Atmospheric Sciences and Climate (1992-1996), the Global Ocean-Atmosphere-Land System Panel (1994-1996), the Panel on Model-Assimilated Data Sets for Atmospheric and Oceanic Research (1989-1991), the Committee on USGS Water Resources Research (1988-1993), and the Advisory Panel for the Tropical Ocean/Global Atmosphere (TOGA) Program (1984-1985).

### VICE-CHAIRMAN

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### MEMBERS

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**Dr. Stanley A. Changnon** has pursued and directed atmospheric and hydrospheric research for 45 years. He directed the atmospheric research program of the Illinois State Water Survey for 25 years and served as the Survey's Chief for six years. As Chief Emeritus, he also serves as a Professor of Geography and of Atmospheric Sciences at the University of Illinois. For three decades he has also directed his own firm specializing in applied climate studies and assessments of operational and research programs. His diverse research interests include investigations of weather and climate extremes such as floods, droughts, and severe storms; climate variability and change; studies of how weather affects agriculture, water resources, society, and policy; relationships between weather and the insurance industry; and the development and use of weather modification. He promoted the development of the nation's network of six regional climate centers and also served as the Illinois state climatologist for 12 years and as the first director of the Midwestern Climate Center. He has authored more than 700 publications including

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**Dr. Richard E. Hallgren** is Executive Director Emeritus of the American Meteorological Society (AMS) after having served as Executive Director of the AMS from May 1988 to January 1999. Dr. Hallgren's research interests are cloud physics, atmospheric electricity, and meteorological systems. Previously, he served as Director of the National Weather Service, Associate Administrator of Environmental Monitoring and Prediction in NOAA, Assistant Administrator for Environmental Systems in ESSA, and Manager, Systems Engineering, IBM Corporation. Dr. Hallgren has served as President of the AMS and as Permanent Representative of the United States to the World Meteorological Organization. He has served on many NRC committees, including the Panel on Climate Observing Systems Status, Board on Global Change, Committee on Earth Studies, and Committee for a Study on "Bits of Power: Issues in the Transborder Flow of Scientific Data."

**Dr. James E. Hansen** is Head of NASA's Goddard Institute for Space Studies, and received his Ph.D. in physics from the University of Iowa in 1967. Dr. Hansen's research interests include radiative transfer in planetary atmospheres, interpretation of remote sounding of planetary atmospheres, development of simplified climate models, and three-dimensional global climate models, study of climate mechanisms such as the role of clouds in climate and the study of current climate trends from observational data and projections of man's impact on climate. Dr. Hansen is a member of the National Academy of Sciences.

**Dr. Douglas G. Martinson** is an Adjunct Professor at the Lamont-Doherty Earth Observatory of Columbia University. Dr. Martinson's primary research foci are the oceans and their role in climate. In particular, he studies the interactions of air, sea, and ice in high-latitude oceans, and investigates how these interactions govern the distribution of sea ice, and how changes in sea-ice cover can affect the world's deep-ocean circulation and global climate. Martinson's research includes both modeling and observational studies in polar regions, typically during winter months, from ships or camps set up on the sea ice. He is also interested in the relationship between oceans and climate over longer time scales, typically focusing on the role of high-latitude oceans in the onset and termination of the ice ages. Dr. Martinson was previously the Chairman of the NRC Panel on Climate Variability on Decade-to-Century Time Scales.

**Dr. Raymond Najjar** is an Assistant Professor at the Pennsylvania State University. His broad area of expertise lies in the role of the ocean in global biogeochemical cycles and climate, air-sea gas exchange, and biogeochemical dynamics of estuaries. More specifically, a central focus of his research is the role of the ocean in global biogeochemical cycles and climate. Najjar makes inferences about the marine carbon cycle by synthesizing and analyzing large data sets for carbon dioxide and related chemical species, particularly dissolved oxygen and nutrients. Another research interest of Najjar is paleoceanography where he is involved in three projects related to past ocean circulation and anoxia. Dr. Najjar is a member of the Joint Global Ocean Flux Study and has authored numerous articles in both U.S. and foreign scientific publications.

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**Dr. Lynne D. Talley** is a Professor of Oceanography at the Scripps Institution of Oceanography at the University of California, San Diego. Dr. Talley's expertise and research interests lie in general ocean circulation, hydrography, theory of wind-driven circulation, and ocean modeling. Dr. Talley has an extensive NRC committee background, having served previously on the Global-Ocean-Atmosphere-Land System (GOALS) Panel and the Panel to Review the Jet Propulsion Laboratory Distributed Active Archive Center (DAAC). She is a member of the American Geophysical Union (AGU), American Meteorological Society (AMS), and Oceanography Society. Dr. Talley was a National Science Foundation Presidential Young Investigator in 1987.

**Dr. Anne M. Thompson** received her Ph.D. from Bryn Mawr College in 1978. Dr. Thompson's research areas include atmospheric chemistry-modeling and measurements of tropospheric trace gases. Her special interests cover remote sensing of tropical ozone, air-sea gas exchange, ozone in convective systems, prediction of tropospheric ozone changes, and simulation of pre-industrial troposphere. She is a member of the American Geophysical Union (AGU) and the American Meteorological Society (AMS). She has been honored with the NASA/GSFC's Outstanding Performance Award, Special Act Award, Quality Increase Award, Peer Award, and NASA's Exceptional Achievement Medal.

**Dr. Andrew J. Weaver** is a Professor and Canada Research Chair in Atmospheric Science in the School of Earth and Ocean Sciences, University of Victoria. His research interests lie in the area of contemporary and paleocean/climate modeling and analysis. Dr. Weaver has been involved as a Lead Author in the United Nations IPCC second and third scientific assessment of climate change, as well as a member of the National Research Council's Ocean Studies Board, Committee on Major U.S. Oceanographic Research Programs. Dr. Weaver currently serves on the United Nations World Climate Research Program Working Group on Coupled Modeling and the Advisory Committee for Climate Science of the Canadian Climate Program Board. In 1997, he was awarded the NSERC EWR Steacie Memorial Fellowship.

**Dr. Eric F. Wood** is a Professor of Civil and Environmental Engineering at Princeton University, where he has taught since 1976. He received his Sc.D. in civil engineering from the Massachusetts Institute of Technology. His areas of research include hydroclimatology with an emphasis on land-atmospheric interaction, hydrological remote sensing, modeling the terrestrial water and energy budgets over a range of scales and hydrologic impact of climate change. Dr. Wood is a member of the NRC Board on Water Science and Technology (WSTB) and the Climate Research Committee's parent body the NRC Board on Atmospheric Sciences and Climate (BASC). He is a member of the Council and a fellow of the American Meteorological Society (AMS) and a fellow of the American Geophysical Union (AGU). He has received the AGU Robert E. Horton Award, the AMS Horton Lectureship, and the Princeton Rheinstein Award.

### NRC STAFF

**Dr. Peter A. Schultz** is a Senior Program Officer with the Climate Research Committee in the Board on Atmospheric Sciences and Climate, as well as the Committee on Global Change Research. Dr. Schultz has directed a number of studies at the NRC, including work pertaining to global change research policy, climate observations, climate modeling, decade-to-century-scale climate research, and the GEWEX program. Previously he was a scientific analyst for the NOAA Climate Analysis Center, where he studied global-scale relationships between climate and vegetation. He has also conducted research examining hydrologic output from general circulation models as well as research involving integrated assessment modeling of climate change.

**Mr. Carter W. Ford** is the Project Assistant for the Climate Research Committee and the Panel on Improving the Effectiveness of U.S. Climate Modeling in the Board on Atmospheric Sciences and Climate. He has been involved in a wide variety of NRC projects, including studies pertaining to high-end climate modeling and the GEWEX program. Prior to BASC, Mr. Ford served with the NRC's National Weather Service Modernization Committee. He holds a B.A. in International Studies from Miami University (Ohio).