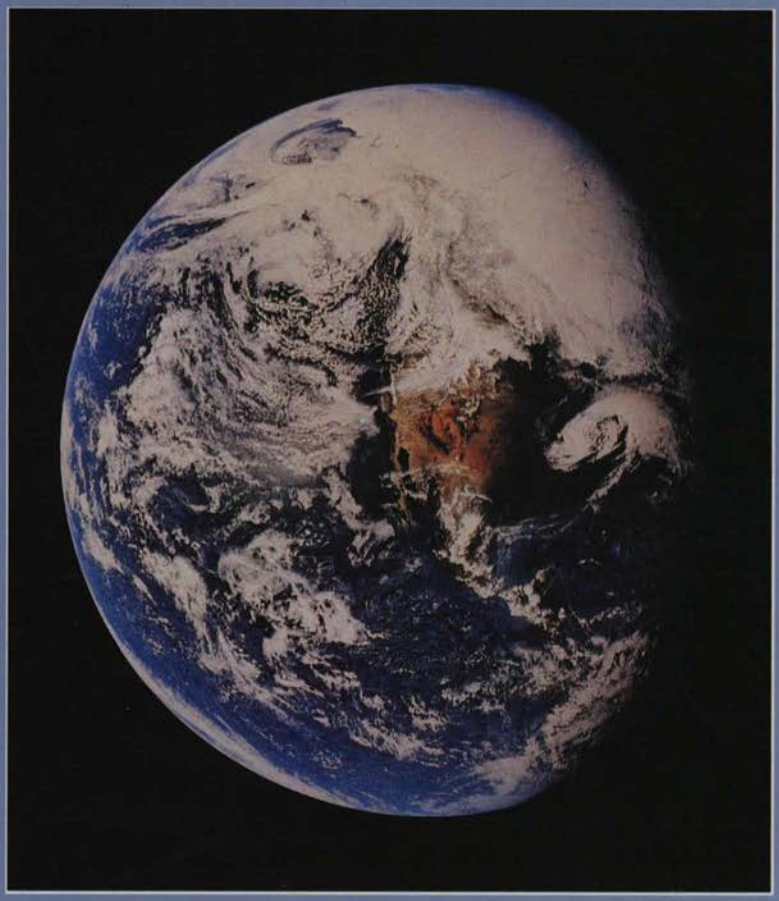
Our Changing Planet:

The FY 1994
U.S. Global Change Research Program



A Report by the
Committee on Earth and Environmental Sciences
of the Federal Coordinating Council for Science,
Engineering and Technology

A Supplement to the
President's Fiscal Year 1994 Budget

This photograph of the Earth was taken from the Apollo 16 Spacecraft. Much of the Earth is heavily cloud covered. A portion of the United States from the Great Lakes to Southern California, including the Rocky Mountain area, is visible. The North American coastline from Southern Mexico to Alaska can be seen. (Courtesy of NASA.)

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WASHINGTON, D.C. 20506

MEMBERS OF CONGRESS:

I am pleased to forward with this letter "Our Changing Planet: The FY 1994 U.S. Global Change Research Program," a report prepared by the Committee on Earth and Environmental Sciences (CEES) of the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET) to supplement the President's Fiscal Year 1994 Budget.

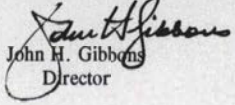
This report outlines a FCCSET Initiative for an accelerated, focused research strategy designed to reduce key scientific uncertainties and to develop more reliable scientific predictions upon which sound national and international policies and responses to global change can be based. The budget proposes $1.5 billion for the U.S. Global Change Research Program in FY 1994.

President Clinton and Vice President Gore have described a strategy for moving America's investments in science and technology in a ". . . new direction to build economic strength and spur economic growth." The U.S. Global Change Research Program is an important element of this strategy. The President and the Vice President have identified the importance of investments in research to better understand global warming, ozone depletion and other phenomena important to local, regional and global environments and have noted that "This research is essential if we are to fully assess the damage mankind is doing to our planet and take effective action to address it."

The approach of the U.S. Global Change Research Program recognizes the profound economic and social implications of responding to global environmental changes and advances U.S. leadership on this issue. The report outlines a careful blend of ground- and space-based efforts in research, data gathering, and modeling activities, as well as economic research, with both near- and long-term scientific and public policy benefits. In FY 1994, the Program will add an explicit focus on assessment, seeking to improve our understanding of the state of scientific knowledge and the implications of that knowledge for national and international policymaking activities.

I want to take this opportunity to highlight the recent advances made by the Program toward documenting, understanding, and predicting global environmental change. Research supported by the Program has given us a better understanding of the processes that regulate the total earth system. These advances have included greatly improved estimates of the rates of global deforestation, identification of sinks for excess carbon dioxide and methane in the global carbon budget, an improved predictive understanding of the El Niño Southern Oscillation cycle, mapping of the plume of sulfur dioxide associated with the eruption of Mt. Pinatubo, and detection of ozone decreases throughout the year in both southern and northern latitudes.

I believe that the report, and the process that produced it, provide an exemplary model of a coordinated, integrated research strategy and a sound basis for planning. I would like to thank Dr. Frederick M. Bernthal, Chairman of the CEES, and Dr. Robert Corell, Chairman of the CEES Subcommittee on Global Change Research, for the outstanding leadership they have provided in the development of this report and the guidance of the U.S. Global Change Research Program.



John H. Gibbons
Director

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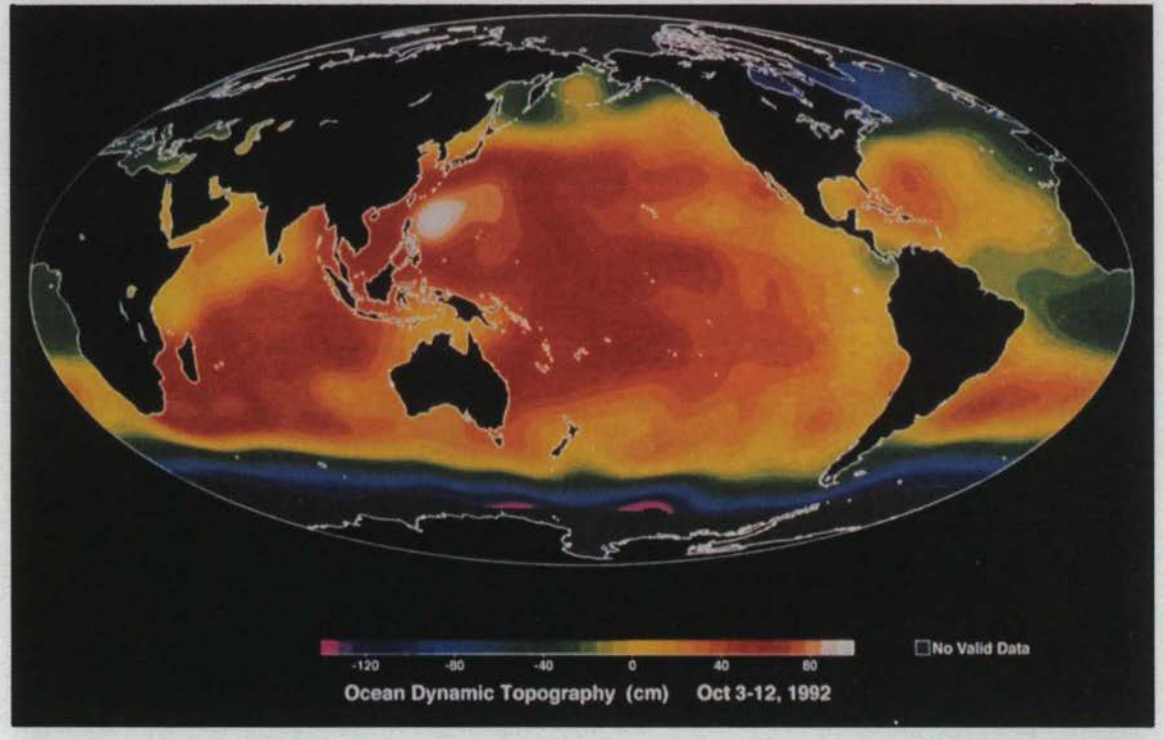
Global ocean dynamic topography determined from 10 days of TOPEX/ Poseidon altimetry data. These data provide the first ever view of the world ocean circulation. (Figure courtesy of NASA.)



Executive Summary

- In their February 1993 report entitled *Technology for America's Economic Growth: A New Direction to Build Economic Strength*, President Clinton and Vice President Gore identify the importance of investments in research to better understand global warming, ozone depletion, and other phenomena important to local, regional, and global environments.

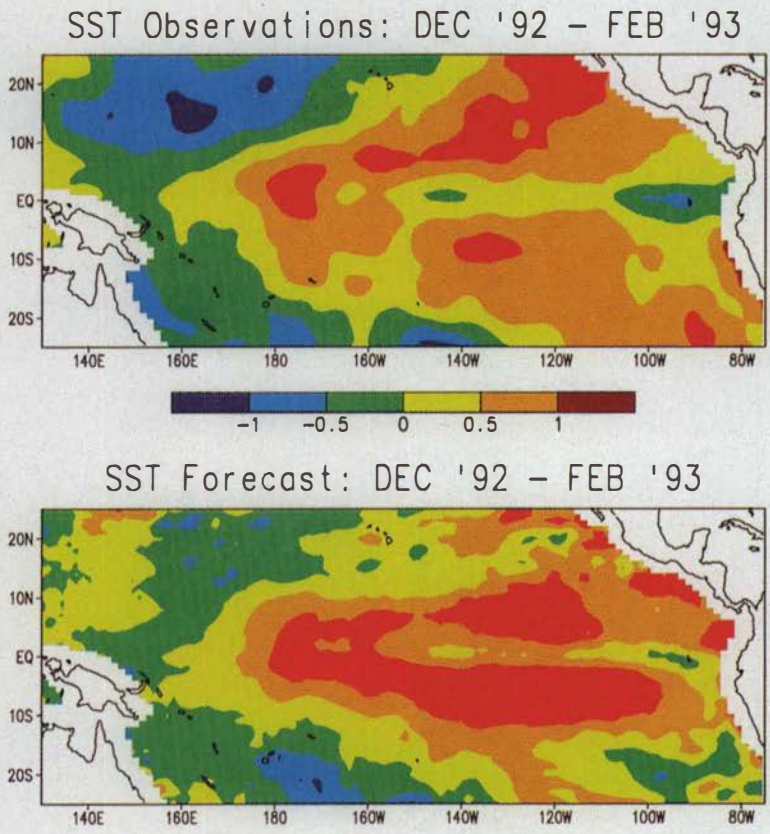
- Since its inception, the U.S. Global Change Research Program (USGCRP) has been implemented as both a source of sound scientific information to support national and international decisionmaking and as a focus for multinational collaboration in the development and application of new scientific insights and technological advancements to practical problems of economic development and environmental stewardship.

- The President's FY 1994 Budget request for the USGCRP sustains a U.S. commitment to the underlying scientific premise that the Earth can be viewed as a single, integrated system whose behavior can be anticipated in order to support national and international policy formulation and decisions relating to natural and human-induced change in the global environment and their regional impacts.

- In that context, the FY 1994 USGCRP will continue to address the following critical Earth-system priorities: Climate Change and Greenhouse Warming; Seasonal to Interannual Climate Prediction; Stratospheric Ozone and UV-B Radiation; Ecological Change and Biodiversity; Human Dimensions, including Economics; International Cooperation; and Education and Public Awareness.

- The President's FY 1994 Budget request for the USGCRP is $1.47 billion, an increase of $149 million or 11% over the FY 1993 appropriated level. This increase is primarily associated with: (i) continued implementation of the space-based component of the USGCRP, including NASA's Earth Observing System (EOS) program; (ii) implementation of the field phases of major research programs of the World Climate Research Programme (WCRP) and the International Geosphere-Biosphere Programme (IGBP); (iii) initiation of an expanded effort to understand the impact of climate change on terrestrial and marine ecosystems; and (iv) significant expansion of USGCRP support for researchers and institutions advancing the state of Earth-system modeling and prediction, including initial U.S. support for the establishment of an International Research Institute for Climate Prediction called for by the U.S. at the United Nations Conference on Environment and Development (UNCED), held in Rio de Janiero in June 1992.

- The FY 1994 USGCRP request is effectively linked to other FCCSET initiatives. The High-Performance Computing and Communication Initiative, for example, will provide the computing power and network capacity required for analysis of the vast amounts of data on global environmental issues and for the implementation of global and regional predictive models.



Coupled Model Project/NMC

SST Observations and Forecast

Comparison of observed (top panel) to forecasted (bottom panel) sea surface temperature anomalies (departures from normal) in the tropical Pacific Ocean for the winter season December 1992-January 1993. Temperatures are depicted from -1.5 °C (dark blue) to +1.5 °C (red). The El Niño warm event of 1992-1993 is recognized by warmer-than-normal waters in the eastern Pacific. While the two figures differ somewhat in detail, the general pattern and intensities are well resolved. The experimental forecast, generated six months in advance by the National Meteorological Center (NMC) of NOAA, was one of the first modeling efforts to correctly predict the resurgence of warmer-than-normal waters off the west coast of the Americas one year after the 1991-1992 El Niño warm event. (Figure courstesy of NOAA/NMC.)

I. Introduction

In their February 22, 1993 report entitled: *Technology for America's Economic Growth: A New Direction to Build Economic Strength*, President Clinton and Vice President Gore describe a strategy for moving America's investments in science and technology in a "...new direction to build economic strength and spur economic growth." The U.S. Global Change Research Program (USGCRP) is an important element of this strategy. The February 1993 report identifies the importance of investments in research to better understand global warming, ozone depletion, and other phenomena important to local, regional, and global environments. The U.S. Global Change Research Program has been implemented as both a source of sound scientific information to support national and international policy formulation and decisions relating to natural and human-induced changes in the global environment and their regional impacts.

The U.S. Global Change Research Program was conceived and developed to be policy-relevant and, hence, to support the needs of the United States and other nations by addressing significant uncertainties in knowledge concerning natural and human-induced changes in the Earth's environment. The USGCRP responds to the guidance provided by the Federal Coordinating Council for Science, Engineering and Technology (FCCSET), the Office and Management and Budget (OMB), and to the requirements for interagency planning, implementation, and accountability set forth in the Global Change Research Act of 1990 [P.L. 101-606].

The USGCRP is designed to produce a predictive understanding of the Earth system to support national and international policymaking activities across a broad spectrum of global, national, and regional environmental issues. To fulfill this goal, the USGCRP is organized into four parallel but interconnected streams of activity:

- **Observations and Data Management** through the establishment of an integrated, comprehensive, long-term program of Earth-system observations on a global scale and associated data management activities;

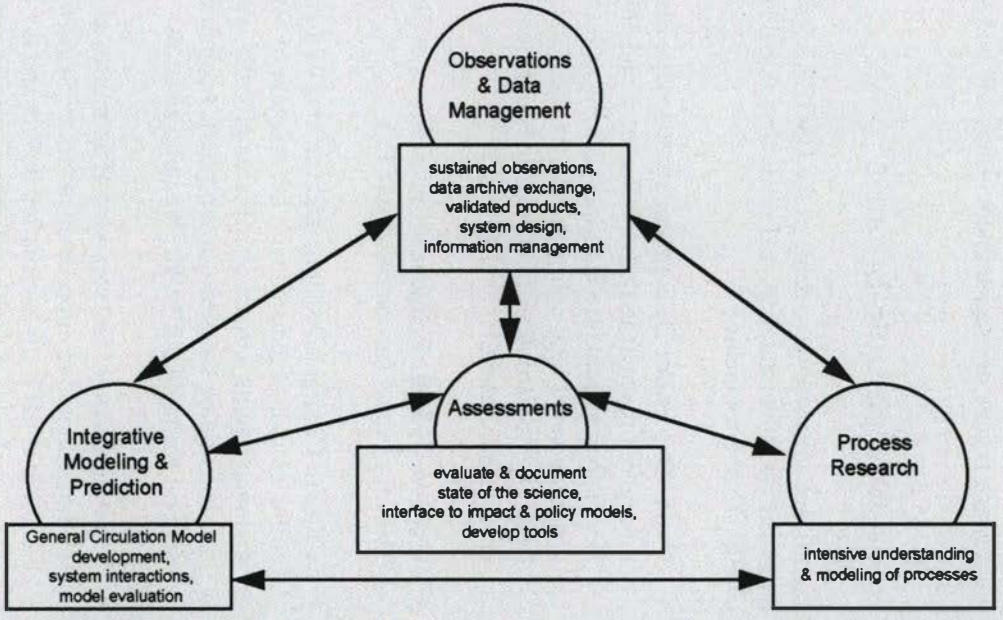
- **Process Research** through a program of focused studies to improve the knowledge of the physical, geological, chemical, biological, social, and economic processes that influence and govern Earth-system behavior and the knowledge of the impact of global change on human health and activities;

- **Integrative Modeling and Prediction** through the development and application of integrated conceptual and predictive Earth-system models that improve the understanding of the interactions among Earth subsystems which range from the atmosphere, oceans, and land surfaces to economics and human dimensions;

- **Assessments** that document the state of scientific knowledge and address the implications of the science of global change for national and international policymaking activities over a broad spectrum of global and regional environmental issues.

The functional architecture for the organization of the USGCRP, as depicted in Figure 1, illustrates the interconnections between these four streams of activity. The seven science elements: (i) climate and hydrologic systems; (ii) bio-geochemical dynamics; (iii) ecological systems and dynamics; (iv) Earth-system history; (v) human interactions; (vi) solid Earth processes; and (vii) solar influences, still serve as the foundation for the USGCRP; however, as the need to develop cross-disciplinary programs has evolved, the four activity streams are being used to integrate across these science elements. This architecture leads to coordination across agencies of observations and data management, process research, integrative modeling and prediction, and assessment activities among scientists from different disciplines.

Figure 1
U.S. Global Change Research Program
Functional Architecture



Participating USGCRP agencies continue to maintain control over their USGCRP budgets. The Committee on Earth and Environmental Sciences (CEES), through its Subcommittee on Global Change Research (SGCR), provides interagency coordination, implementation, management, and oversight, including interagency review of programmatic needs and budgets.

Recent Accomplishments

Significant advances were made in the USGCRP last year toward documenting, understanding, and predicting global environmental change. Examples include:

- **Ozone Depletion:** Detection of stratospheric ozone decreases throughout the year in both the Southern and Northern Hemispheres in mid- to high-latitudes through satellite observations of total column ozone by the Total Ozone Mapping Spectrometer (TOMS), and confirmation with in-situ measurements;

- **Carbon Budget:** Refinements in estimates of global carbon sinks for excess carbon dioxide (CO_2);

- **Climate Change:** Detection and tracking of a large plume of sulfur dioxide associated with the eruption of Mt. Pinatubo and mapping its aerosol distribution globally, and successfully predicting the global tropospheric cooling and stratospheric warming due to Mt. Pinatubo aerosols;

- **Climate Change:** Development of an improved understanding of the quantitative importance of stratospheric/tropospheric aerosols in the Earth's radiation budget and the impacts they have on climate, possibly offsetting, at least regionally, some of the tropospheric warming due to greenhouse gas increases;

- **Climate Change:** Identification of episodes of abrupt climate change in the Earth's natural climate systems; through the study of ice cores form the second Greenland Ice Sheet Project (GISP2), atmospheric changes from one climate mode

to another have been shown to occur naturally in less than a single decade.

- **Climate Prediction:** Significant advances in the development and use of interactively coupled ocean-atmosphere global climate models needed for successful modeling and prediction of seasonal through century time-scale climate variations;

- **Climate Prediction:** Improvement of the observations, understanding, modeling and prediction of the El Niño-Southern Oscillation (ENSO) cycle, including a successful prediction of an El Niño event a year in advance; and

- **Deforestation:** Improvement in the estimates of rates of tropical deforestation. These rates are now reduced from earlier estimates.

The FY 1994 Program

The President's FY 1994 request for the USGCRP is $1,475 million, which represents an increase of $149 million, or 11% above the FY 1993 appropriation level.

The President's FY 1994 Program has been shaped by concern for the kind of environment that is passed on to the next generation, as expressed through:

(i) U.S. commitments made in support of the United Nations Conference on Environment and Development (UNCED), held in Rio de Janiero in June 1992;

(ii) the scientific information requirements identified during development of a Framework Convention for Climate Change;

(iii) the findings and recommendations of the Intergovernmental Panel on Climate Change (IPCC), particularly the 1992 update;

(iv) priority requirements for U.S. contributions to the international global change research activities of the World Climate Research Programme (WCRP) and the International Geosphere-Biosphere Programme (IGBP); and

(v) the findings and recommendations of a series of national plans and recommendations, workshops, and Congressional hearings focused on more clearly defining the global change information needs of decisionmakers, such as the final report of a "Joint Climate Project to Address Decision Makers' Uncertainties," prepared by Science and Policy Associates, Inc. with support from a number of CEES agencies.

Enhancements in the FY 1994 USGCRP

The President's FY 1994 request for the USGCRP includes augmented funding for a number of high-priority programs and projects implemented in previous years.

- **Observations and Data Management:** Funding for global observations and data management is planned at an aggregate level of $652 million for FY 1994, an increase of 9.6% over the FY 1993 appropriated level. Of this amount, $324 million is to support ground- and space-based observational programs and $328 million will support activities in global change data and information management. The Earth Observing System (EOS) will continue to be developed for a planned initial launch in 1998, with the ultimate goal of providing at least 15 years of global observations from satellites and making those data, which are vital to reducing uncertainties, available to researchers worldwide. Both ground- and space-based observations and studies will provide data for determining: the atmospheric distribution of greenhouse gases, aerosols, and ozone; the terrestrial sources and sinks of carbon and the effects of changes in land use; the variability of atmospheric thermodynamic states and their changes (e.g., temperature and moisture structure, clouds and precipitation); and changes in the extent of polar ice sheets and in the strength and pattern of the ocean circulation. Considerable

effort will be put into incorporating a broad spectrum of existing data sets, including newly accessible foreign data sets, into the global change data management stream to substantially enhance the data available to the scientific community. The FY 1994 program also includes a major advance in research and development for the improvement of data archiving and accessing systems and interagency implementation of the Global Change Data and Information System (GCDIS). Related international development and planning will also be continuing in many nations and international organizations on a comprehensive Global Climate Observing System (GCOS), the associated Global Ocean Observing System (GOOS), and the newly proposed Global Terrestrial Observing System (GTOS), as part of the overall integrated database needed for achieving an improved predictive capability. The President's FY 1994 request for the USGCRP includes support for new efforts to enhance the ongoing efforts of CEES agencies to expand observations of environmental conditions and processes that may serve as definitive early indicators of greenhouse warming.

- **Process Research:** Funding for process research is planned at an aggregate level of $681 million for FY 1994, an increase of 11.3% over the FY 1993 appropriated level. Process research is a critical component of the Program, and is designed to substantially enhance the understanding of key processes that control climate and other aspects of global environmental change. These activities will be augmented in FY 1994 to provide needed support for major international field experiments and analytical studies associated with implementing the International Geosphere-Biosphere Programme (IGBP), the World Climate Research Programme (WCRP), and the Human Dimensions Programme (HDP). Of central importance is continued U.S. support for programs aimed at improved understanding of processes that control: (i) the global carbon cycle; (ii) the role of clouds and aerosols in atmospheric radiation budgets; (iii) the role of the ocean in climate change; and (iv) the relationships between global change and terrestrial/marine ecosystems, especially feedback processes. This latter research area was identified as

requiring special attention by CEES agencies in FY 1994 and beyond. It is also one in which extensive international collaboration will be necessary.

- **Integrative Modeling and Prediction:** The FY 1994 program in predictive Earth-system modeling is planned at an aggregate level of $143 million, an increase of 18.2% over the FY 1993 appropriated level. Earth-system modeling research for FY 1994 will focus on: (i) accelerating the pace of coupled model development and testing; (ii) increasing coordination among federal agencies and researchers in model development, application, and experimentation; (iii) improving regional resolution of models used in the prediction of climate change; (iv) developing and testing new computational tools for future applications; and (v) U.S. support for an International Research Institute for Climate Prediction (IRICP) called for at UNCED. The IRICP will apply recent advances in observing, understanding, and modeling the El Niño-Southern Oscillation cycle to practical problems of economics and development.

- **Assessment:** In FY 1994, the USGCRP will add an explicit focus on assessments, to provide a function for coordinating and reporting the current state of knowledge about the implication of global change for national and international policymaking activities. This new assessment function covers a broad spectrum of global and regional environmental issues. The assessment function for FY 1994 is budgetarily embedded within the other three program streams of the USGCRP (i.e., observations and data management, process research, and modeling). Assessments will also provide the mechanism for utilizing the state of knowledge to provide to decisionmakers the best current indices of potential impacts.

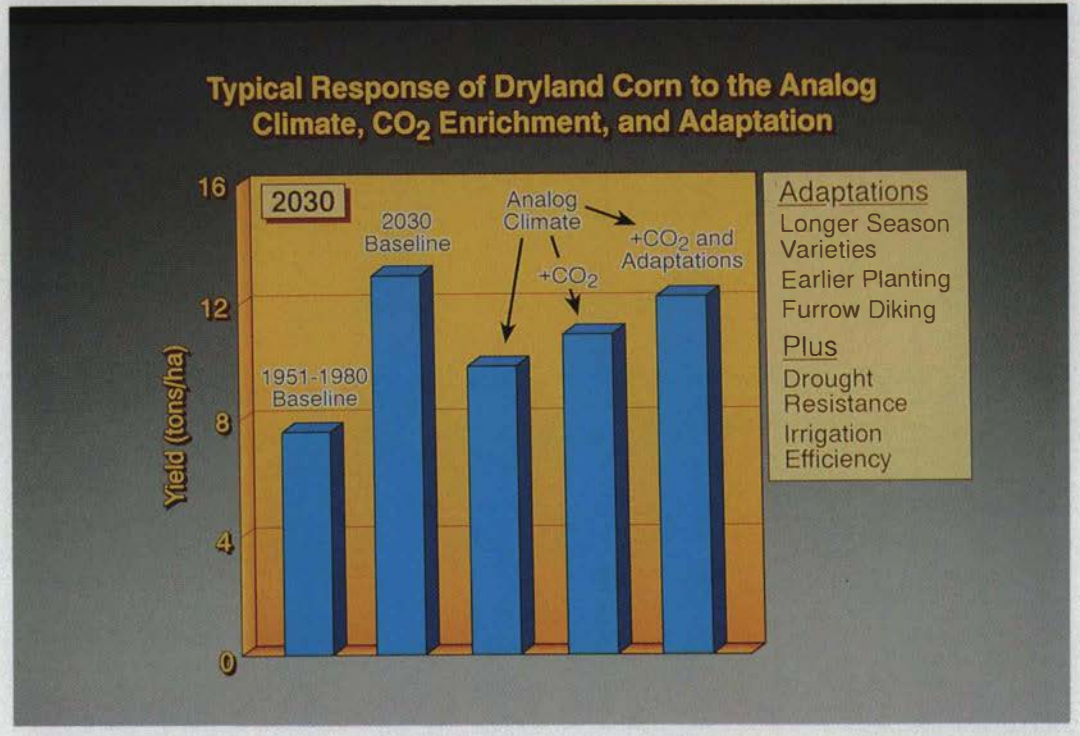
New Directions

Plans are currently being reviewed within the Clinton-Gore Administration to significantly broaden the scope of research and technology development required to respond more fully to global

change challenges. Building on the new assessment component, the goal of this program expansion is to enable the U.S. Government to conduct end-to-end (integrated) assessments of global change issues upon which sound policies can be identified, adopted, implemented, and maintained at regional, national, and international levels. End-to-end assessments will require the integration of basic research on Earth-system processes with that on environmental and socio-economic impacts and effects studies and research on mitigation and adaptation strategies and technologies. This more inclusive global change program will be effectively linked with a pro-active policy apparatus at the highest levels of Government. The outlines of this new approach and the details of its impacts on the USGCRP in the form of a multi-year research plan will be delivered to Congress with the President's FY 1995 Budget.

MINK Chart

Computed response of dryland corn in the MINK (Missouri-Iowa-Nebraska-Kansas) region to climatic changes hypothesized for A.D. 2030. First, from now to 40 years hence, improved farming and technology raise the present yields. Then changing climate to that of the Dust Bowl lowers yields, enrichment of the CO_2 in the air raises them, and finally adaptation raises them further. The model does not include the potential effects of declining water resources. (From Rosenberg and Crosson, courtesy of DOE.)



II. Major Priorities in Global Change Research

The underlying scientific premise of the U.S. Global Change Research Program involves a view of the Earth as a single, integrated system whose behavior can be anticipated in order to support national and international policy formulation and decisions relating to natural and human-induced changes in the global environment and their regional impacts. Although the long-term, overarching goal of the Program is to understand and predict features of the integrated Earth system, the efforts of the CEES agencies at any one time can be viewed in the context of a set of crosscutting, policy-relevant priorities. These priorities will evolve over time, as new scientific insights are developed, existing problems are resolved, new opportunities are identified, and decisionmaking requirements change. Currently, the U.S. Global Change Research Program is addressing the following critical Earth-System priorities:

- Climate Change and Greenhouse Warming
- Seasonal to Interannual Climate Prediction
- Stratospheric Ozone and UV-B Radiation
- Ecological Change and Biodiversity
- Human Dimensions, including Economics
- International Cooperation, and
- Education and Public Awareness

The following sections summarize the status of USGCRP research activities in each of these topics:

Climate Change and Greenhouse Warming

The continuing emissions of carbon dioxide, methane, and other gases resulting from human activities are altering the natural composition of the atmosphere. For example, the global concentration of CO_2 has increased by more than 25% since the start of the

Industrial Revolution, and its rate of increase is increasing as world population and dependence on energy from fossil fuels are growing. These composition changes affect the climate by enhancing the natural trapping of infrared radiation (the greenhouse effect), adding a warming tendency to the influences of volcanic eruptions, variations in the incoming solar radiation, human generation of aerosols, and natural variations in the ocean-atmosphere system.

Observations indicate that over the 110 years since adequate records have been kept, the global average temperature has risen about 0.5 °C, which is roughly comparable to sustained natural fluctuations in the past (e.g., the Medieval warming). Paleoclimate studies have indicated that abrupt natural climate changes can occur within decades.

Recent studies have indicated that the most sensitive area for temperature changes caused by increases of greenhouse gas concentrations is the region of the Earth's atmosphere between the upper stratosphere and the lower thermosphere. These regions, located at altitudes of 40 km to 250 km, are cooled by an increase in greenhouse gas concentrations. Large temperature decreases (more than 10°C) may have already taken place. For example, polar mesospheric cloud formation has monotonically increased during this century, an increase that is believed to be related to decreasing temperatures in this region.

Important areas of process research in climate change include studies of the radiation balance, and of the carbon and hydrologic cycles of the Earth. Programs such as the Earth Radiation Budget Experiment (ERBE), the Stratocumulus Transition Experiment (ASTEX), and the Atmospheric Radiation Measurement (ARM) program are leading to increased understanding of the crucial role of clouds on the Earth's radiation balance. In addition, natural and man-made aerosols are believed to play a major role in the Earth's radiation balance. Knowledge of the carbon cycle is paramount as human activities continue to add CO_2 to the atmosphere. Recent studies have suggested that many Northern Hemisphere ecosystems may be accreting carbon. Essential parameterizations of the hydrologic cycle elements have been developed and are presently being tested.

A predictive simulation of the potential climatic cooling from the Mt. Pinatubo volcanic eruption was in good agreement with the observed half degree Celsius cooling, increasing confidence in the ability of atmospheric models to predict short-term phenomena. An increasing number of simulations include both interactive atmosphere and ocean representations; there is increasing evidence of the potential for centennial-scale climate variability in long simulations with these models. Adaptation of global models for the new massively parallel computers is showing promise, which should allow more detailed studies over the next several years.

Seasonal to Interannual Climate Prediction

Research supported by the USGCRP has shown that a highly significant factor influencing seasonal to interannual variations in the climate system is the El Niño-Southern Oscillation (ENSO) cycle. The ENSO cycle is an oscillation of relatively warm and cold waters with a variable period of two to seven years in the tropical Pacific Ocean and which causes concomitant response of the global atmosphere. Climate variations often have widespread and sometimes devastating impacts. The ENSO cycle influences the onset and intensity of the Asian and Indian monsoons; the frequency, severity, and paths of storms in the Pacific; the viability of commercial fisheries off the coast of South America; and the occurrence of short-term regional droughts and floods in many parts of the world, including the U.S. Some of the adverse impacts of these climate fluctuations could be avoided or reduced by successful forecasts of ENSO.

Before the 1980s, ENSO events were not understood or modeled adequately. Over the past few years, however, the ability to observe, understand, and model the ENSO cycle has greatly improved under the leadership of the USGCRP supported Tropical Ocean Global Atmosphere (TOGA) Program of the WCRP. The TOGA Tropical Atmosphere Ocean (TAO) Array, currently being completed, continuously monitors changes in the upper ocean and at the sea surface at 69 fixed points spanning the Pacific basin. The recently completed TOGA Coupled Ocean Atmosphere Response Experiment (COARE) in the western

Pacific Ocean produced an unprecedented four-month-long set of intensive observations that will be analyzed and should significantly improve the understanding of the air-sea interactions in the western Pacific that control the ENSO cycle. The TOGA Program on Prediction (T-POP) has achieved significant improvements in dynamical modeling that have led to demonstrations of skillful forecasts of the ENSO cycle a year or more in advance.

These recent advances can provide the nations of the world with a remarkable opportunity to apply new capabilities to practical problems of economics and development. In FY 1994, the U.S. will greet this opportunity by moving forward with plans to establish an International Research Institute for Climate Prediction (IRICP), an integrated effort dedicated to accelerating progress in understanding the predictability of ENSO-related climate variations and to the systematic production and utilization of experimental forecasts. The IRICP will be underpinned by the continuation of a vigorous research program aimed at furthering the observing, understanding, and modeling of seasonal to interannual climate variations.

Stratospheric Ozone and UV-B Radiation

As a consequence of the release of chlorofluorocarbons (CFCs), halons, and methyl bromide, a set of catalytic chemical reactions are being stimulated that are depleting stratospheric ozone. Because ozone absorbs the highly energetic components of incoming solar radiation, reductions in ozone concentration allow increasing levels of ultraviolet radiation to reach the Earth's surface, impacting the health of humans and other animals and adversely affecting some plants and micro-organisms.

Over the past two years, detailed reviews of both satellite and ground-based data sets have been conducted. Global data provided by the Upper Atmosphere Research Satellite (UARS) and the Shuttle ATLAS missions have provided new insight into the chemistry and dynamics of the stratosphere. These have indicated that reductions on the order of 5% per decade have been occurring since the 1970s in the ozone concentration over the

mid-latitudes of the Southern Hemisphere and decreases nearly as large have also occurred in the Northern Hemisphere. In addition, the extent of the very strong springtime ozone depletion in the Southern Hemisphere has increased, and there is emerging evidence that the Northern Hemisphere may be primed for a similar springtime depletion.

Even if the control measures of the amended Montreal Protocol were to be implemented by all nations, the abundance of stratospheric chlorine—a major factor in the depletion of ozone—is expected to increase for the next several years, peaking at about the turn of the century. Observational and modeling programs will document changes and test the understanding of the mechanisms involved. These programs will also provide the basis for predicting the extent of future depletion.

To determine how ozone changes are affecting UV radiation at the Earth's surface, the surface UV measurement program will be significantly augmented. The U.S. will play a leading role in updating the international ozone assessment and in the continuing special evaluation of methyl bromide, which has a number of important societal uses, but which, if emissions were cut back, would significantly reduce the bromine-induced contribution to ozone depletion.

Ecological Change and Biodiversity

Quantitative assessments of the potential consequences of changes in climate and land use on ecosystems require improved ecological information. Ecosystem research is focused on processes and factors affecting ecosystem organization, structure, functioning, diversity, and responses to global change. These responses include interactions among different ecological processes associated with systems ranging from individual species to entire landscapes and the physical and biogeochemical feedbacks of these on the physical climate system. In addition, it is essential to examine the response of ecological systems to different forcing factors acting simultaneously. These types of targeted ecological process research will provide the science to underpin environmen-

tal assessments, policy analyses, and response strategies to mitigate adverse global environmental changes or adaptive strategies to cope with such changes.

Examples of targeted ecological research include studies of non-sustainable land-use management on such factors as species composition, population dynamics, genetic drift, etc. Cooperative international pilot studies of this nature are ongoing in Africa, Asia, and Latin America. These studies focus on: (1) reproductive biology and demography of key plant and animal species; (2) molecular studies of genetic drift due to climate change; (3) community dynamics of tropical deforestation and forest fragmentation; (4) tropical forest population dynamics in relation to short and long-term climatic variability; (5) effects of elevated levels of atmospheric CO_2 levels on temperate and tropical plants; and (6) biophysical and geochemical studies of coastal and near-shore communities.

Planning is underway to better focus terrestrial ecology research on improving our understanding of key ecological processes. Elements of the planned research focus on: (i) quantifying terrestrial carbon fluxes and changes in carbon content of biotic and soil components of terrestrial ecosystems (i.e., estimating magnitudes of sources and sinks in representative ecosystems); (ii) understanding ecosystem functional responses to changing atmospheric CO_2 and other trace gas concentrations and changing climate; (iii) understanding ecosystem feedbacks on global climate change; and (iv) understanding changes in the pattern of vector-borne diseases. Ongoing research through ecological networks will improve understandings of linkages and feedbacks among integrated processes.

Human Dimensions and Economics

Research on the human dimensions of global change, including economics, provides insights into the forces that drive global change, the impact that those changes have on human health and activities, and actions to respond to potential global change. The dynamic processes through which humans alter the natural

environment can be better understood and more accurately predicted through analyses of the complex interactions among individuals and the institutions they create as well as interactions between human and natural systems. Enhanced research on the economics and other human dimensions of global change improves the knowledge base from which to examine the probable impacts and consequences of myriad strategies for preventing, mitigating, and adapting to global changes. Foremost among those strategies are policies being considered by the U.S. government unilaterally and in concert with other nations of the world.

Economics research that is part of the USGCRP does not provide policy recommendations for decisionmaking, but provides the foundation for policy analysis by developing and analyzing methodologies and economic models to support an integrated framework for assessing policy options. The major research priorities for economics are: (i) economic forces and global environmental change; (ii) impacts and adaptation of economic systems; (iii) the value of information and decisionmaking under uncertainty; (iv) the economics of technology and practice linked to global environmental change; and (v) policy and policy instrument evaluation. The USGCRP coordinates economics activities with the CEES Subcommittee on Economics Research on Natural Resources and the Environment.

Current research also addresses the responses of socio-economic systems to environmental changes. Economic models have been refined to assess how national economies will evolve in response to changing levels of greenhouse-gas emissions, both under "business-as-usual" conditions and as altered by various policies. These modifications have permitted evaluation of the costs of meeting emission-reduction goals through various means. One recent study examined a range of cost-assessment models and concluded that the predicted costs of meeting emission-reduction goals varied considerably and that much of that variation was explained by differences in assumptions. Models that assumed rapid economic growth in business-as-usual scenarios, for example, tended to predict higher emission-reduction costs than did models that assumed more modest growth. Model structures also have been found to be important. For example, models

focusing on technologies implemented at specific energy sources generally calculate lower costs for emission reduction than do macroeconomic models relying on aggregated data. Additional refinements to modeling efforts include studies to analyze and use aspects of decisionmaking under uncertainty. Work also is proceeding on more effective evaluation and inclusion of non-market benefits, such as wilderness and biodiversity, and the air and water filtration provided at no cost by natural ecosystems, such as forests and wetlands.

Research on the responses of economic systems to changing environmental conditions also has focused on the impacts on different sectors. Research is needed to study how agricultural production will be affected by changing temperature and precipitation patterns; comparable studies need to be undertaken for forestry and other natural resource-dependent activities such as tourism. A line of research common to many different modeling considerations is the prediction of improvements in technology and its diffusion, which is an integral part of forecasting over the time scales of decades to centuries. Research on economic and other social implications of climate change for coastal areas has been broadened to include all climate-related phenomenon such as changes in storm tracks and storm surge, and sea level rise. The work has highlighted the interrelated nature of the environmental decisions facing low-lying nations, which stand to be adversely affected by future changes in climate. These types of inquiry are critical elements in efforts to include human systems in integrated assessment models, a focus for FY 1994 and beyond. These models are being improved and expanded to better represent the continual feedback through which people and institutions alter environmental systems and respond to changes in those systems.

Increasing attention is being focused on the interactive aspects of how humans change the natural environment. Research emphasis is now being placed on the factors that lead people to change their use of forests and other environments. Processes of human-influenced global change, including deforestation and desertification, have been found to be markedly heterogeneous, which underscores the need for identifying a balance of targeted response strategies. Several long-term studies are underway at

ecological research sites to compare consequences of alternative human use strategies over several decades and provide a basis for evaluating human use.

Research in the cognitive and behavioral sciences has sought to clarify the processes through which people and institutions perceive and respond to changes in the environment. These lines of research have explored the role of scientists and the popular media as communicators of information about global change, and they have highlighted the differential impacts that various types of information have on individuals and groups with different socio-economic and demographic characteristics. Research also has focused on identification of the different ways that people perceive and respond to environmental changes at local, regional, and global scales and their varying reactions to catastrophic as opposed to more gradual yet more certain forms of change.

Research on the health effects associated with global change under the USGCRP includes studies on CFC chemical replacements and UV (ultraviolet) radiation. The objective of the proposed research on CFC replacements is to investigate the metabolism and toxicity of the HCFCs, including HCFC-22, HCFC-123, HCFC-124, HCFC-125, HCFC-132b, HCFC-134a, HCFC-141b, and HCFC-142b. The UV studies are examining UV-induced skin cancers and immunosuppression in laboratory animals; the effectiveness of repair of DNA damage in human cells resulting from exposure to UV radiation; and the effects of UV radiation and photosensitivity in people using commonly prescribed and over-the-counter drugs and topical agents.

International Cooperation

It has long been recognized that international cooperation is essential to the success of the USGCRP and that of global change research programs of other countries. Developed and developing countries must work together to apply their scientific expertise, data, observational capabilities, and resources to develop a comprehensive approach which will enable us to fully understand the processes that underlie global change. In particular, the

categories "ecosystems and biodiversity", "human dimensions and economics", and "education and public awareness" address primarily factors which must be studied in-situ outside of the United States. To this end, the U.S. actively coordinates the planning, development, and implementation of the USGCRP with complementary global change research programs of other countries and international organizations. The current U.S. program places special emphasis on improving regional cooperation.

The results of the international global change research effort (of which it is estimated the U.S. conducts about one-half) support a broad range of international policy-related activities. These include the Montreal Protocol on Ozone; the Framework Convention on Climate Change; and the Convention on Biological Diversity. The U.S. strongly supports the Intergovernmental Panel on Climate Change (IPCC) which assesses the science and economics of, impacts of, and response strategies to climate change.

Hundreds of scientists from more than fifty countries have participated in the recent IPCC science assessments on climate change (1992) and the World Meteorological Organization (WMO)/United Nations Environment Programme (UNEP) assessments of ozone (1991). These assessments provide timely insights into the most pressing scientific questions that must be addressed to help resolve global change policy issues and thus in turn assist the USGCRP in setting priorities. The USGCRP coordinates U.S. participation in IPCC Working Group #1 on scientific assessments and climate change, and provides input to Working Groups #2 on impacts, adaptation, and mitigation, and #3 on cross-cutting economic and other issues.

Two other examples of international collaboration in global change research are the regional institutes for global change research and the International Research Institute for Climate Prediction. The first of the regional institutes for global change research is the Inter-American Institute for Global Change Research (IAI). The United States and sixteen other countries of the Americas have over the past year signed the Agreement Establishing the IAI which is expected to become operational in

the latter half of 1993. It is expected that the IAI will have a multi-disciplinary scientific agenda which will support the geographically focussed needs of the region as well as regional implementation of global programs. In addition, the U.S. is interacting closely with the Commission of European Communities (EC) and with interested African countries to initiate development of similar regional cooperation in Europe and Africa and with Asian countries to advance regional cooperation through an Asia-Pacific Global Change Research Network.

All three regional efforts are expected to support and be supported in turn by the IGBP/WCRP/HDP System for Analysis, Research and Training (START). Over the past year the U.S. has contributed to the sponsorship of and has actively promoted participation by U.S. scientists in a number of international scientific workshops and planning meetings to further develop the START program and the three regional networks outlined above. The U.S. also has many ongoing research projects on global change with Japan, carried out through the auspices of the bilateral U.S./Japan Science and Technology Agreement. A bilateral U.S./Japan Workshop on Global Change Mitigation and Adaptation Technologies was held recently to identify areas for future joint collaboration.

The U.S. is also moving forward with plans to establish an International Research Institute for Climate Prediction (IRICP) to advance the science of seasonal to interannual climate prediction and to provide the mechanisms for the application of climate information in support of sustainable economic growth and development. These predictions will be developed and distributed to application centers and operational agencies in the participating countries which will apply the predictions to local conditions, evaluate their utility, and recommend enhancements, as appropriate.

Coordination of global change research is achieved on a global scale through both formal and informal mechanisms. A number of the key U.S. global change research programs are coordinated with their counterpart programs in other countries through three major multilateral programs: the World Climate Research

Programme (WCRP); the International Geosphere-Biosphere Programme (IGBP) and the Human Dimensions of Global Environmental Change Programme (HDP). These programs are conducted under the aegis of United Nations specialized organizations (e.g. WMO and UNEP); UNESCO's Intergovernmental Oceanographic Commission (IOC); and the non-governmental International Council of Scientific Unions (ICSU).

The U.S. agencies which fund global change research also coordinate their funding efforts informally with those of funding agencies in other countries through the International Group of Funding Agencies for Global Change Research (IGFA). IGFA is presently preparing a summary of national resources being made available for global programs in order to identify any gaps, shortfalls, or overlaps. IGFA is also considering ways to most appropriately meet the needs identified for international planning/ project offices for the WCRP, IGBP, and HDP and will, at its next meeting in September 1993, consider ways to encourage increased participation in global change research by developing countries, especially in Asia and the Pacific.

U.S. agencies with responsibility for space-based Earth observation programs that support global change research coordinate these programs with those of other countries through the informal international Committee on Earth Observations Satellites (CEOS). A major objective of CEOS is to enhance communications and responsiveness between satellite operators and international scientific user groups. CEOS works closely with IGFA and interacts with interested international organizations such as the WMO, UNEP, and IOC. In December 1992, CEOS approved an updated data policy that aims to provide satellite data from all missions to global change research scientists for the cost of fulfilling the users' requests.

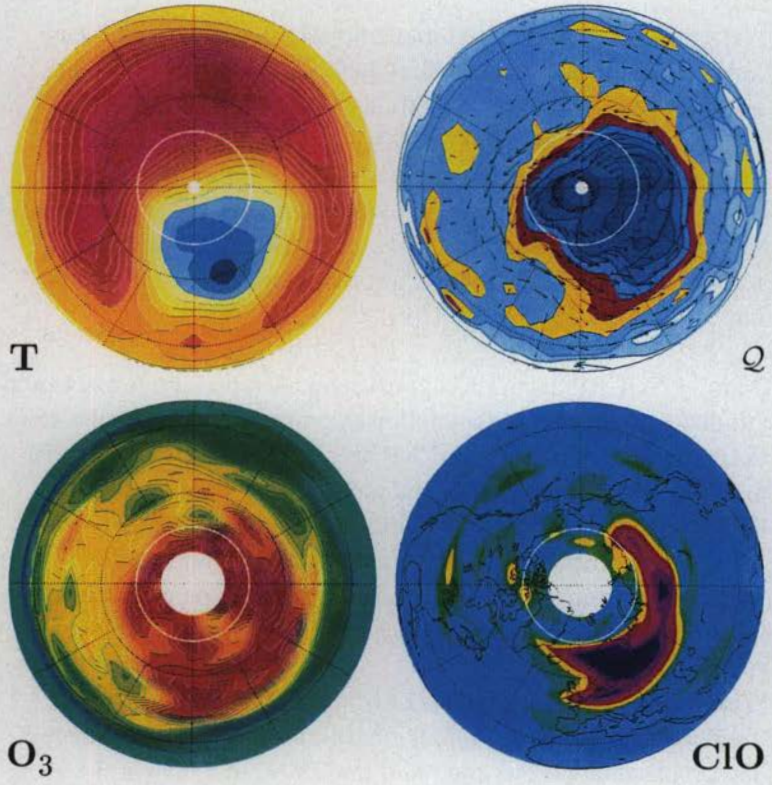
Education and Public Awareness

Global change education and public awareness efforts are critical for (i) developing an informed and literate public able to utilize the results of scientific research and make wise resource management choices; and (ii) encouraging the training of future scientists

and program managers and implementers in multi-disciplinary approaches to monitor and study global change and to define applications of predictive capability over the next decade and beyond. To accomplish these tasks, the SGCR agencies are continuing to pursue a coordinated program of global change education activities that will provide multi-disciplinary opportunities at all grade levels (from K-12 through college and graduate and post-graduate school) and informal continuing and public education.

Many USGCRP agencies support school curriculum projects and graduate and post-graduate fellowship programs in global change research. In FY 1994, USGCRP agencies are planning regional training sessions on climate and global change topics ranging from natural climate variability to marine ecosystem responses. USGCRP agencies are also involved with the publication of monographs and supporting teaching materials on global change, which are supplied to science teachers nationally.

The USGCRP Education Task Group has proposed and was funded for phase one of a four-phase education initiative including preparation (1993) and build-up (1994) to a National Town Hall Meeting on Global Environmental Change (1995), to coincide with the 25th Anniversary of Earth Day. A training material package on global environmental change is being prepared and will be used in a pilot training program for educators in a two-day Pacific rim workshop during 1993. Topics to be covered include: natural climate variability, greenhouse gases, ozone depletion, sea level rise, terrestrial and marine ecosystem responses, and environmental ethics. Workshop attendees will conduct similar workshops in preparation for the national teleconference on Earth Day 1995.



UARS Data

The 11 January 1992 distribution in the Northern Hemisphere of ClO (the predominant form of reactive chlorine responsible for stratospheric ozone depletion), temperature (T), ozone (O_3), and potential vorticity (Q). These data were acquired by the Microwave Limb Sounder Instrument (MLS) of the Upper Atmosphere Research Satellite (UARS). (Images courtesy of NASA.)

III. USGCRP Program Overview

Background

The U.S. Global Change Research Program is designed to lead to an improved predictive understanding of the Earth-system to support national and international policy formulation and decisions relating to natural and human-induced changes in the global environment and their regional impacts. To fulfill this goal, the Program has developed four parallel but interconnected, streams of activity: (1) Observations and Data and Information Management; (2) Process Research; (3) Integrative Modeling and Prediction; and (4) Policy Relevant Assessments.

The functional architecture for organizing the USGCRP, as illustrated in Figure 1 of the Introduction, illustrates the interconnections between these four streams of activity. Using this architecture as a management tool allows the Subcommittee on Global Change Research (SGCR) to coordinate these four activities across agencies and among scientists from different disciplines.

The U.S. Global Change Research Program is currently funded at $1.3 billion annually and involves 18 departments and agencies of the U.S. Government and Executive Offices of the President. The scope of the research supported by the agencies in the program reflects a broad interest and commitment to understanding the potential causes and consequences of climate and global change. The range of Earth-system phenomena and environmental issues addressed include: (i) human-influenced depletion of the stratospheric ozone layer and the resultant potential increases in surface-level ultraviolet radiation; (ii) natural and human-induced changes in greenhouse gases and aerosols and the resultant changes in global and regional climate and on sea level; (iii) natural variability, including the El Niño-Southern Oscillation

phenomena; (iv) biotic responses to global change and the possible large-scale redistribution of vegetative cover that they may induce, and the feedbacks that these changes may have on further climate change; (v) the impact of human activities and land use change on climate and on the changing abundance of plant and animal species and biodiversity; and (vi) economic and social responses to naturally occurring and human-induced changes in the Earth system, as well as appropriate mitigative and adaptive strategies.

The planning, coordination, and execution of USGCRP research activities are in close association with and in support of the science priorities of the Intergovernmental Panel on Climate Change (IPCC); the related programs of the World Climate Research Programme (WCRP) and the International Social Science Council (ISSC); and the core projects of the International Geosphere-Biosphere Programme (IGBP). The current level of effort underpins the United States' participation in and contribution to the international assessments related to aspects of global change, including: (1) the scientific, impact, and technology-economic assessments of stratospheric ozone depletion that are conducted under the auspices of the Montreal Protocol; and (2) the scientific, impact, and policy-response assessments of the Intergovernmental Panel on Climate Change. U.S. research also supports national assessments of: (1) science issues, such as the local and regional impacts associated with ozone depletion, natural climate variability (e.g., El Niño-Southern Oscillation phenomena), and greenhouse warming; and (2) the economic and social costs of these impacts and of potential response strategies.

The improved understanding of the Earth system is the foundation upon which environmental technologies will be developed to reduce the emissions of greenhouse gases, to enhance their sinks, and to provide the capability to cope with the effects of global change. Research efforts are underway within the U.S. to develop new technologies in areas such as energy, agriculture, water resources, and health.

Program Management and Evaluation

The SGCR is responsible for coordinating the development, evaluation, and review of the USGCRP. The primary responsibility for developing and implementing the projects and program elements of the USGCRP resides with the participating agencies. The organizational arrangement within the CEES/SGCR is based on four Program Working Groups, one for each of the four parallel streams of activity listed above. Integration across these streams of activity is as important as ensuring the quality of effort within each one. To provide that integration, the Chairs of the four Working Groups join the Chair of the Subcommittee on Global Change Research in forming the Executive Committee for the USGCRP. This Executive Committee is charged with providing overall programmatic guidance and direction, while at the same time, representing the interests and responsibilities of the participating agencies. In May 1993, an Office of the USGCRP was established. The Office, working with the Subcommittee Chair, the four Working Group Chairs and the SGCR assists with the coordination of USGCRP program activities across all CEES agencies.

The USGCRP undergoes periodic evaluation of the overall Program in the context of advancing scientific knowledge to determine its continued relevance to the policy process, both domestically and internationally. This independent review involves academic, state, industry, and other groups conducting global change research, such as the National Academy of Sciences.

Proposed and existing projects within the USGCRP are evaluated based on (i) their relevance and contribution to the overall USGCRP goal and objectives; (ii) scientific merit as documented by peer review; (iii) readiness for implementation and likelihood of early results; (iv) potential for and/or progress toward meeting Program milestones; (v) agency approval for inclusion in the USGCRP; and (vi) conformance to data and information management policies. The framework and evaluation criteria are an essential part of the program and budget development strategy of the CEES. They provide the structure through which CEES

evaluates and develops: (1) essential, high priority national and international components of the USGCRP in each fiscal year; and (2) the recommended budgets to support those critical components.

Highlights of the Current Program

Observations and Data Management

The goal of this component of the U.S. Global Change Research Program is to establish an integrated, comprehensive, long-term program of documenting changes in the Earth system and managing the research data efficiently to facilitate the rapid advance of its understanding. Long-term observations of important physical, chemical, biological, economic, and social parameters provide the critical basis for determining when climate and/or global changes have actually occurred and for supporting the development and testing of new predictive capabilities. They also provide the "reality tests" for evaluating models and predictions, as well as identifying new types of processes that must be characterized and incorporated into more representative global models. While space-based technology enables some parameters of the Earth system to be measured on the needed global scales, the program strategy also depends on long-term ground- and ocean-based observation, including the concomitant data management programs.

Long-term observations of the Earth-system are required to document change, gain an understanding of the complex interactions within the system, and distinguish between natural variability and changes caused by human activities. The full USGCRP strategy critically depends on both space-based measurements and long-term ground- and ocean-based observation and data management programs. Long-term observations of important physical, chemical, biological, and social parameters are critical to improving understanding of processes that control the climate and to verification of integrated Earth-system models and their use for prediction studies. Such observations also provide the basis for determining when climate and other global changes have actually occurred.

Recent Accomplishments

- The National Space Policy Directive (7) of 1992 established a comprehensive government-wide coordinating mechanism for the Space-Based Global Change Observing System (SGCOS) program. The SGCOS will provide coordinated space-based observations to help understand the Earth system; improve our ability to detect and document changes in the global climate system; provide a data system to manage information collected by the SGCOS agencies; and continue development and demonstration of new space-based technologies for global change observations and ultimate incorporation into operational systems. A coordinated interagency plan has been developed to ensure that the USGCRP has the measurements required to provide input for policy decisions on global change.

- During the past year, two new satellites have been added to the international suite of space-based environmental observing systems. The Upper Atmosphere Research Satellite (UARS) is providing important information on the concentration and distribution of atmospheric components of profound importance to global climate (such as ozone and chlorine) and the TOPEX/Poseidon satellite altimeter is providing global ocean data which has already been instrumental in tracking a significant ENSO event.

- During the past year, the Earth Observing System (EOS) was restructured in light of FY 1993 USGCRP budget constraints. EOS now consists of a series of different flight platforms; a morning (AM) platform; an afternoon (PM) platform; a series of intermediate-sized chemistry (CHEM) platforms; and two series of proposed smaller spacecraft. An extension of the contract to receive ocean color data and the contribution of Earth radiation budget and lighting instruments for flight on the Tropical Rainfall Measuring Mission and its follow-ons has also been established.

- New data are being analyzed to determine ocean circulation patterns. Altimeter data and synthetic aperture radar (SAR)

data from the European ERS-1 are being analyzed to determine if sea level changes have occurred and to increase the understanding of polar ice dynamics. Trend analyses of sea ice covering a fifteen year period are also underway.

- Many retrospective global change data sets have been made available to the research community. As a result, improvements have been made in determining rates of tropical deforestation and patterns of habitat fragmentation. Interagency efforts have documented rates of change in forest cover and land-use using Landsat Multi-Spectral Scanner (MSS) and Thematic Mapper (TM) sensors. These efforts included the initiation of the North American Landscape Characterization (NALC) project, which will provide coverage of the U.S., Mexico, Central America, and the Caribbean. Related Landsat-based projects have been established to provide spatially referenced land cover and deforestation data sets for the Amazon, Central America, and Southeast Asia. Estimates of deforestation in the Amazon from studies using retrospective data from the 1970s and mid 1980s were within 10% of independent analyses done by the Brazilian Space Agency. A vegetative index produced from Advanced Very High Resolution Radiometer (AVHRR) data has shown that correlations exist between climatic variability and the extent of the desert area in sub-Saharan Africa.

- Satellite observations of total column ozone from the Total Ozone Mapping Spectrometer (TOMS), coupled with in-situ measurements show decreases of total ozone throughout the year in both Southern and Northern Hemispheres in high- to mid-latitudes.

- In addition, global baseline surface monitoring stations show that the rates of increase of several of the ozone-depleting gases have slowed. This change reflects the decreased production and release into the atmosphere of these gases. It is the first evidence of the atmospheric response to production limitations required by the Montreal Protocol and, hence, shows the environmental benefits of these policy decisions.

- The SGCR Long-term Observations and Data and Information Management Working Group has inventoried studies currently underway within the U.S. Government to investigate the flux and impact of UV-B radiation reaching the Earth. In response to the expanding Antarctic ozone hole, the U.S. has also provided instrumentation to begin long-term measurements of UV-B radiation at the Earth's surface in South America and the Antarctic. These instruments will determine the magnitude of the increase, if any, of UV-B reaching the surface due to decreases in stratospheric ozone.

- Management of the data and information system required for global change research is built around the interagency Global Change Data and Information System (GCDIS). Because of the need for integrating widely disparate global data and information from many disciplines over long periods of time, the USGCRP presents major challenges to the traditional manner of managing data and information and has made significant progress in meeting them. The agency commitments are documented in *The U.S. Global Change Data and Information Management Program Plan,* published in September 1992.

- The Tropical Ocean/Global Atmosphere (TOGA) Array, consisting of 69 moorings spanning the tropical Pacific, neared completion with the installation and full operation of 45 moorings. These moorings transmit surface winds and subsurface ocean temperature data back to the United States in real-time via satellite. When completed in 1994, the Array will be capable of producing, for the first time ever, accurate, real-time, basin-wide maps of the meteorological and oceanographic conditions in the tropical Pacific based on in-situ data and, in so doing, will revolutionize the field of observational oceanography. The data from the Array are being assimilated into numerical models that will soon start to be used to begin routine predictions of interannual climate variability in the tropics and over the U.S.

Process Studies

Understanding the processes that govern global change is the second of the major components of the U.S. Global Change Research Program. Along with long-term observations, the characterization of fundamental Earth-system processes provides the scientific underpinnings of the analysis, modeling, prediction, and assessments that aid national and international policy-relevant decisions related to both natural and human-induced changes of the Earth system. Process research involves laboratory studies, small-scale in-situ studies, major field campaigns, and modeling of physical, biological, economic, and social relationships, including important feedbacks. As summed up by the International Geosphere-Biosphere Program:

> "An important facet of process studies is the synthesis of findings into quantitative models of the process under consideration, which can be tested and also can serve as building blocks in the development of global models."

The U.S. Program's process-related research activities consist of the following scientific integrating themes designed to assist the collective efforts of global change scientists throughout the world:

1. Water, Energy, and Sea-Level Change. Investigation of the processes that regulate the global energy and water cycle, namely, those that influence the atmospheric radiation and energy balance, clouds and precipitation, solar forcing, sea-ice, sea-level, the roles of the ocean in climate, land-surface properties (including hydrology), as well as having shaped the paleoclimatic record of these parameters. Among other activities in this area are the major U.S. contributions to the Tropical Ocean and Global Atmosphere (TOGA) Program, the World Ocean Circulation Experiment (WOCE), and the Global Energy and Water Cycle Experiment (GEWEX) of the World Climate Research Programme.

2. Greenhouse Gases, Aerosols, and Ozone. Characterization of the processes that influence the atmospheric concentrations of

the chemical species and aerosols that directly or indirectly influence the local radiation balance and the global energy balance. These processes include terrestrial and oceanic sources and sinks, both human-influenced and natural, of these compounds. The major U.S. contributions to the International Global Atmospheric Chemistry (IGAC) project reside in this activity area.

3. Ecological Systems. Studies of processes and properties that determine the responses and feedbacks to regional and global climate patterns of terrestrial, freshwater, and marine organisms and ecosystems, at different spatial scales, to changes in climate, atmospheric composition, and ultraviolet radiation.

4. Economics and Human Interactions. Examination of the social and economic processes (e.g., population and economic growth) that drive or respond to regional and global environmental changes. This includes characterizing the economic and social factors that influence greenhouse gas emissions; evaluating the potential to mitigate against and adapt to global changes; and characterizing the impacts of global change on human activities and health.

Recent Accomplishments

- Refinements in estimates of global carbon sinks have improved the accounting of "missing carbon." Recent ecosystem studies suggest that some natural and managed ecosystems may be accreting carbon in sufficient quantities to possibly account for some of the "missing carbon."

- The major role played by aerosols on the Earth's radiation balance has been recognized and its influence estimated. Recent studies and model calculations indicate that the cooling effect of aerosols formed from industrial sulfur emissions and biomass burning are of sufficient magnitude, averaged globally, to partially offset greenhouse warming. In addition, laboratory, field, and modeling studies have begun to characterize the role of stratospheric aerosols in the

depletion of the global ozone layer. The eruption of Mt. Pinatubo provided an opportunity to understand these processes better, and to validate radiation balance models.

- New studies are investigating the upper mesosphere and lower thermosphere as sensitive early indicators of global warming. Increases in greenhouse gas concentrations appear to lead to very large temperature changes in these upper atmospheric regions.

- New programs are identifying the effects of clouds on the Earth's radiation budget. The Earth Radiation Budget Experiment (ERBE) provided the first solid observational evidence that on a global annual average, clouds slightly cool the planet. ERBE and the International Satellite Cloud Climatology Project (ISCCP) global data sets are providing critical tests for evaluating cloud and radiation parameterizations in global models. Other programs such as the First ISCCP Regional Experiments (FIRE) Studies, including the Cirrus experiment and Atlantic Stratocumulus Transition Experiment (ASTEX), the Atmospheric Radiation Measurement (ARM) program, and the Central Equatorial Pacific Experiment (CEPEX) are helping to define key physical processes to increase understanding of the role of clouds.

- Knowledge about ecosystem response to climate change and impacts of high levels of UV-B radiation has improved. Growth and survival of marine plankton have been shown to be reduced by exposure to increased levels of UV-B radiation, and this could have major implications within the marine food chain. Research continues to identify responses to increased UV-B for selected species and ecosystems.

- Efforts are underway to improve treatment of regional-scale land-surface processes, particularly hydrology and vegetation, in global models. As a first step in representing vegetation dynamics over continental-scale domains, half-degree (about 50 km) resolution versions of terrestrial ecosystem models have produced approximations of evapotranspiration, net primary productivity, and nitrogen mineralization.

- Advances have been made in the development of economic models to assist national and international decisionmakers in implementing policy to reduce greenhouse gas emissions. Comparison among models which estimate the costs of achieving emission reduction targets show that model results are related to major assumptions regarding population growth, economic growth, and energy end-use improvement. In addition, progress continues toward an integrated assessment of possible responses to climate change. Economists and other researchers are jointly developing methods to estimate both benefits and costs of different alternatives, with special attention to the presence of uncertainty and the possibility of irreversible damage on one hand and high costs on the other.

- The Project Office for Past Global Changes (PAGES) of the IGBP has been established with joint support of the U.S. and Switzerland. This project will coordinate an international effort designed to reconstruct the history Earth's environmental systems in order to provide the test bed for global modeling experiments. Paleoclimate data will also provide insight into ecosystem response to climate change.

Integrative Modeling and Prediction

The third component of the U.S. Global Change Research Program is the building of a predictive understanding of the behavior of the Earth-system on the time scales of primary interest to humans, namely those ranging from seasons through decades and centuries. To accomplish this, a primary objective of the Program is the development and use of integrative models as the central tool for the achievement of constantly improving predictive insight into Earth-system behavior and for relating individual research projects meaningfully to one another.

The overall focus of the Integrative Modeling and Prediction element is the development and verification of comprehensive global models and the continuing improvement of predictions of climatic fluctuations and longer-term climatic changes. Global ocean-atmosphere models which couple general circulation

models (GCMs) of the ocean and the atmosphere are providing early indications of characteristics of the Earth system. Global ocean-atmosphere-land surface models that couple the interactive features of the land surface to those of the oceans and atmosphere will allow more complete treatment of the full hydrologic cycle, especially soil moisture. The next stage of models will add interactive chemistry, including interactive treatment of the carbon cycle and atmospheric ozone. Models that include interactive ecosystem models within complete ocean-atmosphere-land surface models are being developed. These successively improving model generations will reflect the overall advancement in scientific understanding of the Earth system and the comprehensiveness with which it can be represented.

Recent Accomplishments

- The 1991-1992 El Niño event was predicted unequivocally more than one year in advance. The 1991-1992 El Niño event is now thoroughly documented in its magnitude, timing and scope, and the validation of predictive models has been achieved. These modeling efforts are expected to lead to regular experimental forecasts of climate variability on the seasonal to interannual time scales through the developing plans for an International Research Institute for Climate Prediction.

- An ocean GCM has predicted the extent and timing of a recent Kelvin wave pulse, a mass of warm water that travels from the central and western Pacific toward the western coast of South America and contributes to ENSO events. Measurements from the TOPEX/Poseidon satellite substantiate the model predictions of the magnitude and timing of this event, and are tracking the motion of the pulse.

- The U.S. is providing major support for the international Atmospheric Model Intercomparison Project (AMIP). More than two-thirds of 30 modeling groups around the world that are participating have completed initial simulations for the period 1979-1988 as a major step in resolving uncertainties

arising because different models have been giving different estimates of climatic change. Related diagnostic and model intercomparison projects are investigating the causes of the model disagreements, especially the role of cloud-radiation interactions and other feedbacks.

- Ocean and atmosphere general circulation models (GCMs) are being continually improved, and the coupling between the ocean and atmosphere subsystems (GOA) being refined. A realistic simulation of the interannual sea-ice distribution and thickness has also been achieved, and coupled model simulations are helping to explain the relationship of high-latitude warming and oceanic heat transport. Especially important for climatic purposes are multi-century simulations, which are starting to provide insight into the characteristics of natural climatic variations.

- The effects of atmospheric aerosols are being incorporated into general circulation models to improve understanding of how such aerosol effects may be partially counter-balancing the warming from increasing concentrations of greenhouse gases. A global climate model has been successfully used to predict the short-term climatic effects of volcanic aerosols from major natural events, such as the Mt. Pinatubo eruption.

- The Project Office for the Global Assessment Interpretation and Modeling Task Force (GAIM) of the IGBP has been initiated. This task force, an international group well represented by key scientists of the USGCRP, will conduct coupled modeling experiments related to hydrology and terrestrial vegetation to support diagnostics and intercomparisons of ocean and atmosphere models coupled to land surface models and has developed protocols for joint experiments with the WCRP.

- The use of massively parallel processing in global modeling has led to several recent successes as insights are being gained in how to take advantage of these architectures. An ocean model with high spatial resolution has demonstrated its ability to simulate the global oceanic conveyor belt (the multi-

century overturning of the ocean), changes in which may be an important contributor to climate variability. Two major atmospheric models have been restructured for parallel computers. Such results promise researchers new powerful computational capabilities for performing comprehensive global modeling as advances are made as part of the High Performance Computing and Communications (HPCC) Program.

- In preparation for the large amounts of data expected from EOS, significant progress has been made in development and testing of a model-driven data assimilation system for producing data sets which will be useful for climate diagnostic studies and model initialization and validation.

Assessments

The fourth major component of the U.S. Global Change Research Program is assessing the evolving state of scientific knowledge and describing it in policy-relevant terms. These assessments provide a knowledge base for national and international policymaking activities over a broad spectrum of global and regional environmental issues. The principal role of the USGCRP assessment activity is coordinating the utilization, synthesis, and distillation of the results from the preceding three components, in conjunction with all other scientific information.

The CEES Assessment working group provides the mechanisms needed to involve natural and social scientists, and technical experts from universities, government agencies, and industry in conducting national assessments and ensuring full U.S. participation in international assessments, related to some or all aspects of global climate change. The working group also enables implementation of comprehensive, end-to-end assessments of global change, which include the influence of both natural phenomena and human activities on the Earth's environment. Such assessments include the (i) natural sciences, i.e., physical, chemical, and biological forcing, and response of the atmosphere, oceans, and land; (ii) impacts on ecological and socio-economic systems and human

health; (iii) economic costs associated with mitigation and adaptation; and (iv) technical options for adaption and mitigation.

The Assessment working group interacts closely with the Process, Modeling, and Observation working groups. The assessments will incorporate: (i) a critical analysis of the current understanding of processes; and (ii) an assessment of observations, including issues such as information content of algorithms, calibration procedures, and statistical approaches to trend detection, for comparison with predictions of theoretical models and for determining trends. In particular, the natural sciences working group will need to interact with the Modeling group for conducting model intercomparisons, standardizing model experiments, and for establishing a consistent set of policy-relevant model experiments, including evaluating uncertainties due to various emission scenarios. The assessments will identify what is known as well as the key uncertainties and research needs.

The near-term assessment emphasis will be to enhance the U.S. scientific contributions to: (1) the 1994 national global change assessment required by Section 106 of the Global Change Research Act of 1990; (2) the interim IPCC assessment in 1994 on the relative radiative effects of different greenhouse gases; (3) the 1995 IPCC scientific; impact, adaptation and mitigation strategies; and economics assessments; (4) the 1994 WMO/UNEP scientific, environmental impacts, and technology/economics ozone assessments, which are required by the Conference of the Parties to the Montreal Protocol as part of the basis for the consideration of amendments; and (5) the 1995 comprehensive UNEP global biodiversity assessment. The Assessment working group will ensure transparency, full reporting and complete interagency involvement in the assessment preparation and review process.

The U.S. co-chairs the scientific and technology/economics working groups of the international WMO/UNEP ozone assessments, and the impacts, adaptation, and mitigation working group (WG #2) of the IPCC. Therefore, the U.S. will play a major role in coordinating and preparing these components of the assessment reports. U.S. researchers and program managers are also expected

to make significant contributions to the other components of the ozone and climate change assessments.

Recent Accomplishments

Over the past two or three years, U.S. scientists have played a vital role in the preparation and review of comprehensive international scientific, environmental impacts, technical and economic assessments of ozone depletion and climate change.

- **Ozone Depletion:** Three state-of-the-art assessments were conducted in response to the mandate of the Vienna Convention for the Protection of the Ozone Layer and its Montreal Protocol on Substances that Deplete the Ozone Layer, and published in early 1992. These included: (i) an assessment of our understanding of the processes controlling the present distribution and rate of change of atmospheric ozone; (ii) an assessment of the environmental impacts of ozone depletion; and (iii) an assessment of the technological feasibility and economic costs associated with the substitution of substances controlled under the Montreal Protocol. The U.S. chairs the scientific and technical/economic assessments.

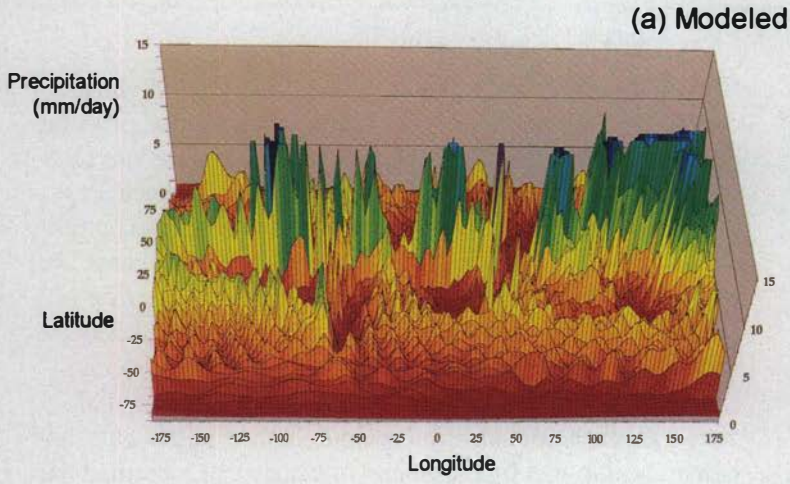
  In 1992, at the request of the United Nations Environment Programme, the U.S. led the preparation of an international assessment of the science, technology, and economics of methyl bromide, whose anthropogenic source has received considerable attention as a contribution to ozone depletion.

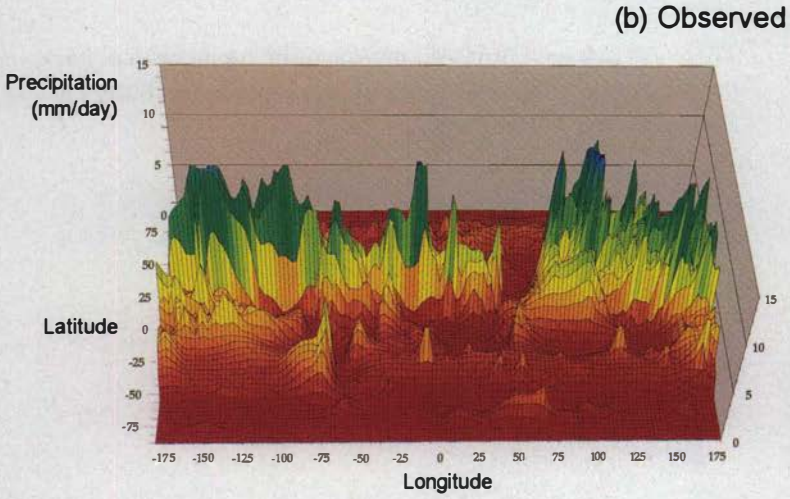
  These assessments were the scientific, technical, and economic foundation for the 1992 Copenhagen Amendments to the Montreal Protocol, which include control measures on methyl bromide.

- **Climate Change:** Three state-of-the-art assessments were conducted in 1990 and updated in 1992 by the Intergovernmental Panel on Climate Change (IPCC), which is sponsored by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP):

(i) scientific assessment that included the full set of climate change phenomena, namely: climate forcing agents; processes involved in climate change; climate model formulation; tests of climate models; simulation of past climate changes; predictions of future climate; past climate record; and physical (sea level) and biological responses to climate change; (ii) impacts assessment that encompassed the full range of potential impacts of climate change, namely: natural and managed (agriculture and forestry) terrestrial ecosystems; hydrology and water resources; oceans, including coastal zones; cryosphere; industrial sectors; human settlements; and human health; and (iii) response strategies that identified the full range of mitigation and adaptation policy options.

These assessments provided the scientific and technical basis for the Convention on Climate Change, which has been ratified by the United States.





Comparison of Modeled (a) vs. Observed (b) Precipitation

Graphical representation of the global average distribution of daily average precipitation for June, July and August, comparing (a) a NOAA Geophysical Fluid Dynamics Laboratory atmospheric model for a simulation of the period 1979 to 1988 using prescribed sea surface temperatures, and (b) a compilation of observations and estimates spanning the period 1920 to 1980. The mapping is a Mercator projection with the Equator across the middle and the Greenwich meridian at the center. Comparing the simulation with observations, many regions show agreement. However, as with all simulations, there still remain areas showing disagreement resulting from limitations in both models and observations. (Graphic courtesy of Lawrence Livermore National Laboratory; model results from NOAA/GFDL Dynamic Extended Range Forecast Model and data from Legates and Willmott, 1990.)

IV. The Proposed FY 1994 USGCRP

Introduction

The President's FY 1994 request for the U.S. Global Change Research Program is $1.47 billion, which represents an increase of $149 million, an increase of 11% over the FY 1993 appropriated level. This increase is primarily associated with: (i) continued implementation of the space-based component of the USGCRP, including EOS; (ii) implementation of the field phases of major research programs of the WCRP and the IGBP; (iii) initiation of an expanded effort to understand the impact of climate change on terrestrial and marine ecosystems; and (iv) significant expansion of USGCRP support for researchers and institutions advancing the state of Earth-system modeling and prediction, including initial U.S. support for the establishment of an International Research Institute for Climate Prediction called for by the United States at UNCED.

FY 1994 Program Enhancements

Observations and Data Management

Documenting global change is the first of the four major components of the USGCRP. The FY 1994 program and budget recommendations of the CEES continue the development and establishment of an integrated, comprehensive, long-term program of documenting Earth-system change on a global scale and managing the data efficiently (see Table 1).

The CEES recommends that the nine agencies involved with observations and data management collectively invest $652 million in FY 1994 for this aspect of the Program, representing an

increase of 9.6% over the FY 1993 appropriation. The range of observations supported by the agencies in the USGCRP reflects a commitment to understanding the potential causes and consequences of: (i) variability in seasonal and interannual climate; (ii) decreases in stratospheric ozone concentrations; (iii) long-term climate change and global warming; (iv) ecosystem changes and loss of biodiversity; (v) changing environmental conditions due to human activities.

In FY 1994, the Observations and Data Management component of the USGCRP continues the development and implementation of an integrated, comprehensive, near-term and long-term program of documenting Earth-system change on a global scale. The following section highlights some of the more significant activities reflected in the President's FY 1994 request:

- The Preliminary and Critical Design Reviews of the instruments of the EOS AM-1 spacecraft will be completed during FY 1994 and FY 1995. Fabrication of the qualification hardware for the instruments will be initiated in FY 1994 as well as planning for major environmental testing to take place in FY 1995.

- Measurements of total ozone from the Total Ozone Mapping Spectrometer (TOMS) will continue, allowing more precise quantification of interannual variability and trends. Measurements of total solar irradiance, ultraviolet and visible solar output from UARS, atmospheric ozone and sulfur dioxide resulting from volcanic eruptions from TOMS and UARS, combined with ground-based measurements of forcing functions will improve the understanding of the Earth's total energy balance and therefore its response to changes in greenhouse forcing. During FY 1994, the TOPEX/Poseidon data are expected to be available for the first analyses of ocean currents and sea-surface elevation, with the early data products finished by the end of the year. Data from SeaWiFS, an ocean color satellite mission launched by industry with a federal government data purchase, will soon be available, allowing global calculations of oceanic productivity derived from ocean color. The ground-based monitoring systems for

atmospheric concentrations of carbon dioxide, methane, nitrous oxide, and CFCs will continue to operate, providing longer time series of data on the observed global changes in atmospheric compositions. The ISSCP will provide more accurate cloud climatologies that are of use to the process research and modeling communities. USGCRP agencies will use the coming year to define a plan for U.S. participation in the Global Ocean Observing System (GOOS).

- During FY 1994, the AVHRR-derived global vegetation index data set will be reprocessed using methods that have recently been developed by performing new calibration and cloud screening techniques and correcting for the effects of solar reflection angles. Analyses from Landsat and Systeme Probatoire d'Observation de la Terre (SPOT) data on the amount and patterns of habitat fragmentation in forested regions undergoing rapid land-use changes will be available for further investigation of their ecosystem and species-level consequences. Landsat and AVHRR data will enable calculations of current terrestrial productivity and net contribution of carbon to the atmosphere from land-use change. Monitoring studies of ecosystem processes and plant and wildlife abundances on federal lands will continue.

- FY 1994 EOS Mission Operations and Systems Verification: the EOS Data and Operations System (EDOS) contract is expected to be awarded in late 1993. The Independent Validation and Verification contract is planned for award early in 1994. This contract will provide for the end-to-end verification of the EOS ground system.

- Data management is intrinsic to every facet of research under the USGCRP, from process studies to modeling to assessment. The data program activities planned for FY 1994 and beyond will provide spaced-based and in-situ data and information for the GCDIS that spans the oceans, atmosphere, cryosphere, biosphere, and related human dimensions. The FY 1994 programs will include research and development for the improvement of data archiving and accessing systems and interagency GCDIS implementation. Pathfinder

data sets from AVHRR, Landsat, and NOAA polar orbiters will be available to the scientific community for analysis. The microwave sounding unit (MSU) data set of tropospheric temperatures will be several years longer, assuring more information on interannual variability. These data sets are being produced in anticipation of EOS measurements, in order to ensure that satellite data can be received, processed, and distributed quickly and efficiently to the community. The National Data Centers operated by the USGCRP agencies will continue to archive and provide data to support ongoing global change research projects.

Process Studies

Understanding the processes that govern and contribute to global change is the second of the four major components of the USGCRP. The FY 1994 Process Studies component of the USGCRP is explicitly designed to focus on (i) critical uncertainties in global change research highlighted by previous USGCRP research and by the National Academy of Sciences' Board on Global Change; (ii) research needs and uncertainties identified by Intergovernmental Panel on Climate Change (IPCC) Science Assessment Reports (1990, 1992); (iii) priorities of the World Climate Research Programme (WCRP); and (iv) Core Programs of the International Geosphere-Biosphere Programme (IGBP).

The CEES recommends that the eleven agencies involved with process studies of global change invest $680 million in FY 1994 for this aspect of the Program, an increase of 11.4% over the FY 1993 appropriation (see Table 1).

The following section highlights some of the more significant activities reflected in the President's FY 1994 request:

- Initiate the Global Energy and Water Experiment's (GEWEX) Continental Scale International Project that will examine the energy budget and hydrological cycle of the Mississippi River watershed.

- Implement the analysis phases of the international Tropical Ocean-Global Atmosphere (TOGA) Project's Coupled Ocean Atmosphere Response Experiment (COARE) activity and initiate the Central Equatorial Pacific Experiment (CEPEX). Both will contribute to an improved understanding of ocean-atmosphere interactions in the tropical Pacific, including the El Niño-Southern Oscillation cycle and the testing of the validity of the tropical "thermostat" hypothesis.

- Implement the World Ocean Circulation Experiment (WOCE) field program. The start of this activity is critical to meeting the overall objective of a "snap shot" of the oceanic circulation, including its heat and mass transport. Understanding the large scale ocean circulation is critical to predicting the timing and rate of greenhouse-gas warming.

- Initiate the International Global Ecosystem Dynamics project in the North Atlantic which will examine the relationship between physical and biological processes in the ocean that govern how the survival and recruitment of marine fishes and zooplankton are linked to climatic change.

- Focus global carbon cycle studies on identifying the sinks of the "missing carbon." An improved understanding is essential to be able to make better predictions of fluxes between known carbon pools to assist with modeling atmospheric CO_2 concentrations that result from specific emission scenarios.

- Expand research on the physical and chemical processes of atmospheric aerosols, snow/ice, and water vapor to improve the understanding of how they affect radiative transfer and global climate change.

- Begin phased deployment of the second ARM program Cloud and Radiation Testbed (CART) site in the tropical western Pacific.

- Increase the emphasis on understanding the formation of global tropospheric ozone—especially at mid-latitudes—by quantifying the indirect radiative role of other greenhouse

gases and the role of human activities (such as biomass burning) in influencing ozone production.

- Develop new Land Margin Ecosystem Research sites; initiate experiments on plant species and ecosystem responses to increased temperatures and/or atmospheric CO_2 levels; continue the development of vegetative-response models on landscape, regional, and continental scales; and establish ties between the U.S. program and similarly focused international programs on terrestrial and coastal ecosystems.

- Conduct paleoclimate studies on processes that cause decade- to century-scale changes. The studies will be used to compare with general circulation model outputs and with recorded historical data.

- Focus economics and other human-dimension research on analyses of how human activities affect natural processes and how individuals and economic, social, and other institutions perceive and respond to changes in natural conditions.

- Initiate additional studies to improve understanding of health impacts of UV radiation, especially its effects on the immune system.

Integrative Modeling and Prediction

The USGCRP has as its unifying goal the achievement of a predictive understanding of Earth-system behavior on time scales of primary human interest (seasons to centuries and beyond) through a comprehensive effort in Integrative Modeling and Prediction (IMAP). IMAP supports a broad program of research to develop, test, and verify models and to conduct the model simulations needed as input for assessment activities and evaluations of model performance. These activities are an important element of the overall international modeling program of the World Climate Research Programme (WCRP).

The CEES recommends that the nine agencies involved in integrative modeling and prediction invest $143 million in FY 1994 for this aspect of the program, an increase of 18.4% over the President's FY 1993 appropriation (see Table 1). The FY 1994 research in Integrative Modeling and Prediction will build upon current activities and strengthen existing programs; some specific examples include:

- Coordinate and support the significant U.S. commitment to an International Research Institute for Climate Prediction (IRICP) for the study of seasonal to interannual climate variation. This internationally-supported research effort will be dedicated to accelerating progress in understanding the predictability of ENSO-related climate variations and to the systematic production and utilization of experimental forecasts.

- Support model intercomparison and analysis programs. Researchers participating in the international AMIP project are completing initial simulations by current general circulation models (GCMs) for the period 1979 to 1988. By comparing model results to observational records, the goal is to determine the strengths and weaknesses of present models and to identify the causes of differences in predictive capabilities as a means of reducing uncertainties associated with the present state of modeling. The international GAIM Task Force will conduct coupled modeling experiments related to hydrology and terrestrial vegetation to evaluate the coupling of ocean and atmosphere models to those of the land surface.

- Intensify examination of the magnitude and patterns of natural variability exhibited in data from the recent to distant past as evidenced in model simulations covering decadal to century, to millennial time scales. Comparison of observations and model results is needed in order to estimate the potential for more definitively identifying early evidence of a greenhouse warming signal.

- Improve the characterization of biogeophysical and biological land-surface processes in GCMs, with an emphasis on a

better representation of processes that may contribute to mid-continental summer drying. Efforts are also underway to improve the resolution of global models, both in the horizontal and vertical dimensions, which should improve the IPCC reference calculations for the 1% per-year transient increase in the CO_2 concentration.

- Build a more fully coordinated and comprehensive modeling program among the agencies and researchers in the U.S. and with related programs abroad. Within the USGCRP, establish a program of model experimentation that more extensively draws upon work achieved within the observations and process research components of the USGCRP, to better provide timely predictive information to the assessment component of the Program.

- Stimulate the development and use of new computational tools for future applications in Earth-system modeling, including increasing use of the newly developed massively parallel computer architectures and related numerical algorithms.

- Accelerate preparation of the tools needed to translate and process satellite data for use in developing and testing global climate models.

Assessments

The fourth and last of the major components of the USGCRP is assessing the state of scientific knowledge and the implications of the science of global change to support national and international policymaking activities over a broad spectrum of global and regional environmental issues. The budget for these activities is, for FY 1994, embedded in the overall budgets of the other three major USGCRP components.

The proposed FY 1994 USGCRP efforts in long-term observations and data management, process research, and integrative Earth-system modeling are expected to produce significant results

for future assessments of global change and to support the policy needs of the United States and other nations regarding global change issues.

In the context of the Montreal Protocol, technology assessments will receive particular attention in the upcoming assessment cycle, because the availability and feasibility of the CFC and halon substitutes will be an important issue now that the phase-out of both CFCs and halons have been accelerated. The ozone science assessment is being closely coordinated with the IPCC assessment of climate change, because lower stratospheric ozone losses are known to be a factor in climate change.

The USGCRP activities will also support national assessments on such issues as local and regional impacts associated with ozone depletion and climate change and potential response strategies. The proposed FY 1994 USGCRP will ensure transparency, full-reporting, and complete interagency involvement in the assessment preparation and review process.

The FY 1994 USGCRP will address the four strategic priorities of global change national and international assessments important to policy issues:

1. **Determining if human-induced global changes have been observed.**

To demonstrate that human-induced global changes have occurred, it is necessary not only to detect that global change has occurred, but also to establish that the cause was the result of human activities rather than natural system interactions and variations. For example, in the case of spring-time ozone depletion over Antarctica, the cause has been established to be the anthropogenic emissions of chlorine- and bromine-containing chemicals (e.g., CFCs and halons). The probable cause of potential climate change is suspected to be increasing atmospheric concentrations of greenhouse gases, primarily CO_2 from human activities such as fossil fuel combustion. To confirm the understanding of the causes of climate change, a blend of long-term ground-based and satellite global observations, process studies,

and model simulations of the paleo and recent historical record is required. The FY 1994 USGCRP incorporates a combination of all these activities designed to improve the understanding of the human-induced changes occurring in the global environment.

2. Predicting future regional and global changes with improved levels of confidence.

The prediction of future regional and global changes with improved levels of confidence requires the development of reliable high-spatial resolution Earth-system models and realistic scenarios of human activities that might influence the Earth system. Thus the FY 1994 research program reflects continued development of Earth-system models and includes studies to improve observations in order to test models. The program also includes extensive investigations into the processes that affect or result from interactions between elements of the Earth system.

3. Determining the impacts associated with predicted changes.

Determining the impacts of global change on the natural environment requires an understanding of terrestrial ecosystems and how they respond to changes in atmospheric composition and climate. The FY 1994 program includes an expanded observation program and increased research to improve the understanding of the biological and physical processes that are directly or indirectly affected by environmental change.

4. Assessing likely responses of economic, social, and other human systems to changing environmental conditions.

The FY 1994 USGCRP places increased emphasis on understanding the human dimensions and economics of global change. Research is focused on social and economic response to environmental change under various policy options. Predicting responses to climate change depends critically on how, for example, the agricultural sector or the energy sector would respond to different climate change scenarios. Other research investigates the ability

to predict technological progress, which is an important assumption in any prediction of the future, especially on the time scale of decades to centuries implied by global change. Yet other research includes the value of information in a decision framework. This research answers questions such as how much a better answer to a particular question, such as how much sea level is expected to rise, would be worth. Finally, much of this research is combined into "integrated assessment models", in which the benefits and costs of a reference case and various policy options can be evaluated.

Cross-Cutting Science Activities

The FY 1994 USGCRP emphasizes coordinated interagency efforts in the following cross-cutting research programs:

Ultraviolet-B (UV-B) Studies

The Federal agencies involved in the USGCRP are currently working to develop a comprehensive, coordinated approach to measuring and monitoring the amount of ultraviolet radiation detected in the "B" spectral range that is reaching the Earth's surface and the effects it will have on the environment and the human population. An inventory was developed in February 1993, of all Federally-sponsored UV-B research projects. The USGCRP agencies are developing monitoring networks and the capability to calibrate measuring devices to assure consistent and accurate data. This will ensure that the USGCRP UV-B-related research milestones reflect the scientific goals and that all these milestones are being addressed through a coordinated national research plan.

Early Detection Studies

The USGCRP agencies are pursuing the possibility of identifying indicators that can detect near-term changes in the global environment, such as in global temperature or sea level, from both

natural and human-induced factors. A comprehensive definition of early detection is currently being developed, and an inventory of all Federally-sponsored early detection research projects will be conducted. Based on the results of this inventory, a national research plan to investigate early detection will be developed and implemented.

Terrestrial Ecology Studies

A coordinated effort on enhanced terrestrial ecology research on global change has been developed with emphasis on understanding key ecological processes. Elements of the planned research focus on: (i) quantifying terrestrial carbon fluxes and changes in carbon content of biotic and soil components of terrestrial ecosystems (i.e., estimating magnitudes of sources and sinks in representative ecosystems); (ii) understanding ecosystem functional responses to changing atmospheric CO_2 and other trace gas concentrations and changing climate; and (iii) understanding ecosystem feedbacks on global climate change.

Seasonal Climate Forecasting

A multinational initiative has been developed to advance the state of climate forecasting and to provide the mechanisms for the application of climate information in support of sustainable economic growth and development. Recent scientific advances in observing, understanding, and modeling the El Niño-Southern Oscillation (ENSO) cycle have resulted in the development of predictive models which have already provided useful predictions several seasons in advance of an incipient ENSO event. As discussed by the U.S. at UNCED, an International Research Institute for Climate Prediction would be established as an integrated effort dedicated to accelerating progress in understanding the predictability of ENSO-related climate variations and to the systematic production and utilization of experimental forecasts. These forecasts will be distributed to application centers and operational agencies in participating countries which will apply this information to local conditions, evaluate their utility, and recommend enhancements as appropriate.

Data and Information Management

Federal agencies involved in the USGCRP are coordinating the documentation of data sets of primary importance to the success of present and future efforts of the USGCRP and of international programs such as the IGBP. Documenting change in the Earth-system environment is accomplished with in-situ and space-based observations and data and information management activities. The goals are to provide the means for the collection, preservation, and access to data and information for use by scientists and researchers now and in the future and to provide data that are documented, calibrated, quality assured, consistent, and available to the researcher.

Private Enterprise-Government Interactions (PEGI)

In May 1990 the CEES, having identified the need to establish interactions with the private sector regarding global change research, established the Private Enterprise and Government Interaction (PEGI) working group to coordinate interactions between government agencies and the private sector in such research. PEGI provides a government focal point for industry, academia, and non-profit organizations to encourage interaction with the federal agencies which are part of USGCRP. Its membership consists of representatives from all agencies involved with global change research.

The private sector currently conducts significant research in the areas of global change phenomena and environmental research, some of it already in conjunction with Federal agency programs. PEGI encourages private sector and government agency interactions to minimize duplication, to focus on key problems and issues, and to bring working-level researchers together. The objectives of such interactions include:

1. Identifying current R&D activities in the private sector related to global change activities and providing mechanisms to inform the private sector of related government sponsored R&D activities.

2. Facilitating information and data sharing.
3. Encouraging resource sharing.
4. Acting as a catalyst in developing opportunities for potential collaborative research projects.

Currently, PEGI is working to identify research that is being conducted by the private sector in the areas of greenhouse gas emissions and the effects, potential impacts, and responses to climate change. PEGI does not provide project funding, but coordinates private sector contact primarily through organizations such as coalitions and associations representing groups of companies with common foci and interests.

An example of federal government and private sector collaboration is the Model Evaluation Consortium for Climate Assessment (MECCA). MECCA is an international global climate research consortium sponsored by industry, academic, and government organizations. Formed in 1991, MECCA's goal is to provide detailed quantification of the uncertainties inherent in climate model projections of greenhouse-gas-induced climate change and to quantify the probable range of future climate change, providing policymakers with information to support risk assessments and identify key topics for future climate modeling research.

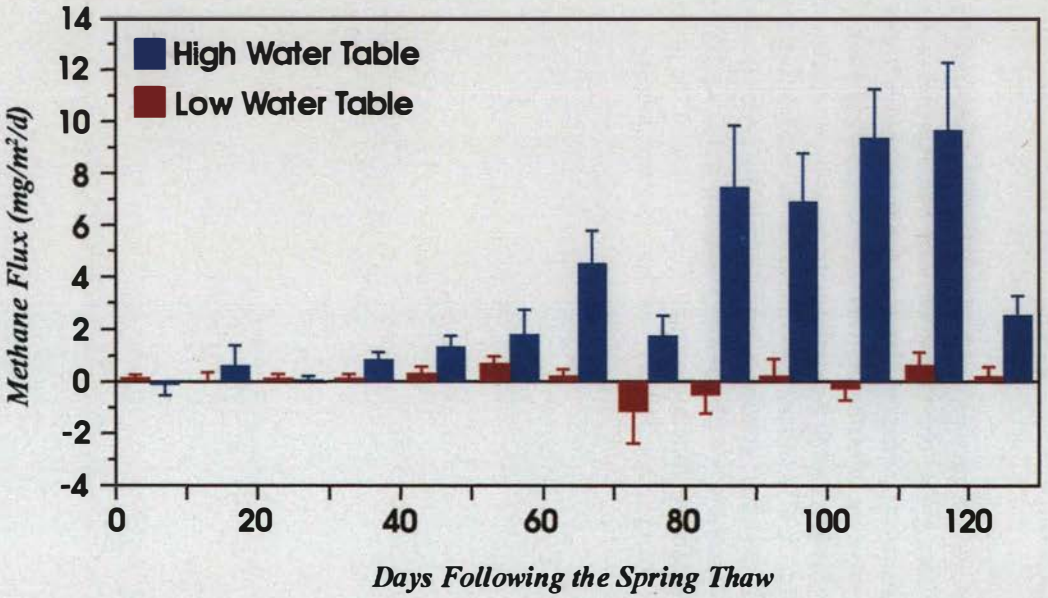
Global Change Research Information Office (GCRIO)

To assist international efforts to become more informed about this issue, the USGCRP began operation in 1993 of the U.S. Global Change Research Information Office (GCRIO) in accordance with the Global Change Research Act of 1990 (P.L. 101-606). The purpose of the legislation was to establish an office "to disseminate to foreign governments, businesses, and institutions, as well as citizens of foreign countries, scientific research information available in the United States which would be useful in preventing, mitigating, or adapting to the effects of global change." The GCRIO will also make available the same information to users within the U.S.

The GCRIO is currently tasked to: (1) determine GCRIO-specific and related global change information holdings and dissemination methods used by various agencies and develop modalities for conveying that information to end-users; (2) facilitate information access by developing a capability to point-to, or store, retrieve, and directly disseminate global change research information; (3) provide customer service to both technically sophisticated as well as low-technology end-users as stipulated in the legislation; and (4) evaluate the functioning and effectiveness of the providing global change information to the end-user community.

Methane Flux

Experimental results of the release of methane (CH_4), in milligrams per square meter per day, from an Alaskan wetland soil in the 120 days following the spring thaw. The experiments were conducted in the Duke University Phytotron using intact soil cores that were incubated under natural environmental conditions assuming either a high or low water table. Because CH_4 is an important greenhouse gas, understanding how predicted precipitation increases in high latitudes may enhance CH_4 release is very important. (Graphic courtesy of the University of Alaska and the EPA Environmental Research Laboratory, Athens.)



V. The Proposed FY 1994 USGCRP Budget

Budget by Agency and by Activity Stream

Table 1 shows the proposed FY 1994 USGCRP budget by agency and by activity stream. The individual agency efforts build upon their respective scientific and technical strengths. The FY 1994 program proposes a total USGCRP budget of: $652 million for observations and data management, an increase of 9.6% over the FY 1993 appropriation; $680 million for process studies, an increase of 11.4%; and $143 million for modeling and prediction, an increase of 18.4%. The USGCRP activities in assessment are budgetarily embedded in the other three activity streams.

Budget by Science Element and by Integrating Theme

Table 2 shows the USGCRP budget by science element. The Program effort in each of the science elements is consistent with the policy needs and scientific priorities identified by the factors which have shaped the FY 1994 program, identified on page 9 of this report.

Table 3 shows the proposed FY 1994 USGCRP budget by integrating themes. The four integrating themes represent areas of global change research which cut across all four activity streams. Emphasis on these themes, within the USGCRP, represent multidiscliplinary efforts to focus global change science on developing improved understanding of the major processes which are key to improving predictions of natural and human-induced changes in the Earth's environment. The four integrating themes, and their proposed FY 1994 budgets are: (i) greenhouse gases, aerosols, and ozone, $443 million, an increase of 10% over FY

1993; (ii) water, energy, and sea level changes, $736 million, an increase of 11.5%; (iii) ecological studies, $249 million, an increase of 10.6%; and (iv) economics and human influences, $22 million, an increase of 14.5%. Activities which do not fit within one of the integrating themes are shown as "Other Research Activities" in Table 3. These include research on solid Earth processes, paleoclimate studies, and some studies on solar influences. The FY 1994 budget proposes $25 million for these activities, an increase of 30% over the FY 1993 appropriation.

Budget by Budget Function

The budget functions of the USGCRP include general science and space technology, defense, energy, natural resources and environment, agriculture, health, and programs of the Smithsonian. These functions each play a vital role in the program and in meeting both the domestic needs of the U.S. in ensuring the economic and environmental health of the nation, and the needs of the international community in developing a better understanding of global environmental issues and the range of global responses that policymakers must address. Table 4 shows the proposed FY 1994 USGCRP budget for these budget functions. Increases of 13% are proposed for the general science, space, and technology function, and 10% is proposed for energy. Other functions with proposed increases include defense, natural resources and environment, agriculture, and health.

Table 1
FY 1993-1994 U.S. Global Change Research Program
Focused Budget by Agency and by Activity Stream*
(Dollars in Millions)

	Total Budget		Observations & Data Management		Process Studies		Modeling & Prediction	
	1993	1994	1993	1994	1993	1994	1993	1994
Agency Totals	1,326.0	1,475.1	595.0	652.2	609.8	679.5	121.1	143.4
DOC/NOAA	66.9	69.9	19.8	19.8	35.0	35.0	12.1	15.1
DOD	6.6	6.8	1.3	1.6	4.1	3.6	1.2	1.6
DOE	89.3	98.3	8.6	10.1	67.4	74.5	13.3	13.7
DOI	37.7	34.0	19.5	19.7	16.0	12.4	2.2	1.9
EPA	25.8	27.5	7.0	6.9	11.1	11.8	7.7	8.8
HHS	1.2	1.5	0.0	0.0	1.2	1.5	0.0	0.0
NASA	921.1	1,013.1	509.5	560.5	346.7	381.3	64.8	71.3
NSF	124.0	169.0	16.9	22.3	92.0	123.1	15.1	23.6
Smithsonian	7.3	7.3	3.3	3.3	3.6	3.6	0.4	0.4
TVA	0.1	0.1	0.0	0.0	0.1	0.1	0.0	0.0
USDA	46.0	47.6	9.1	8.0	32.6	32.6	4.3	7.0

* Total Budget does not include one-time appropriation of $5 million for State Department in FY 1993, as the distribution of funding among proposed projects is still being determined. The budget for the Assessment Stream is embedded in the other three activity streams.

Figure 2
U.S. Global Change Research Program
Focused Budget by Agency

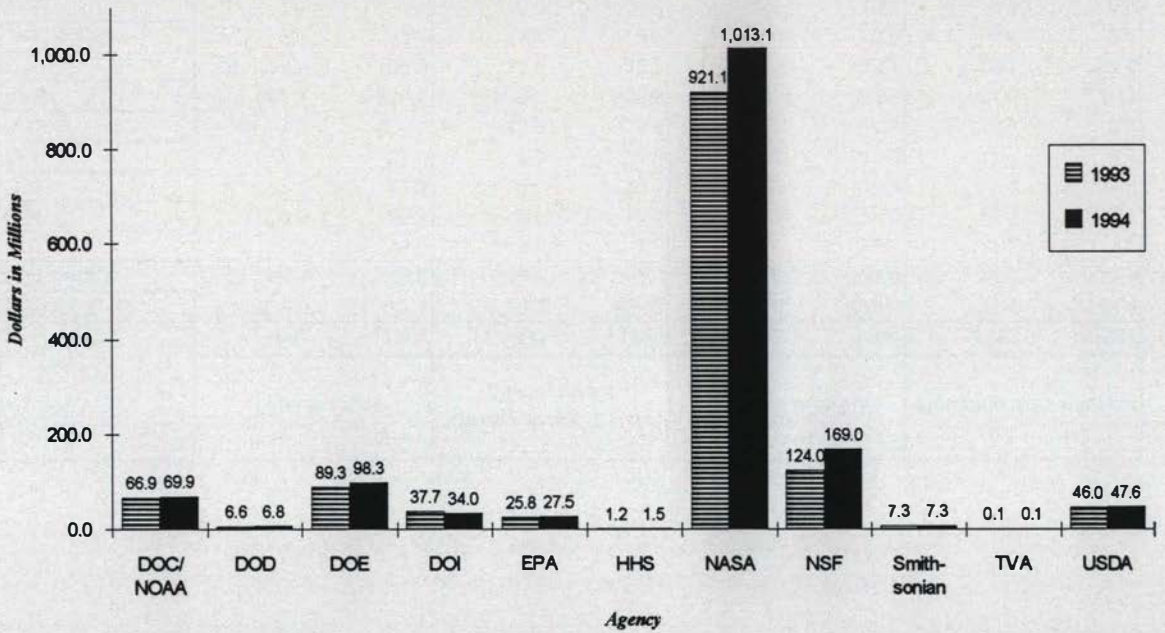


Figure 3
U.S. Global Change Research Program
Focused Budget by Activity Stream

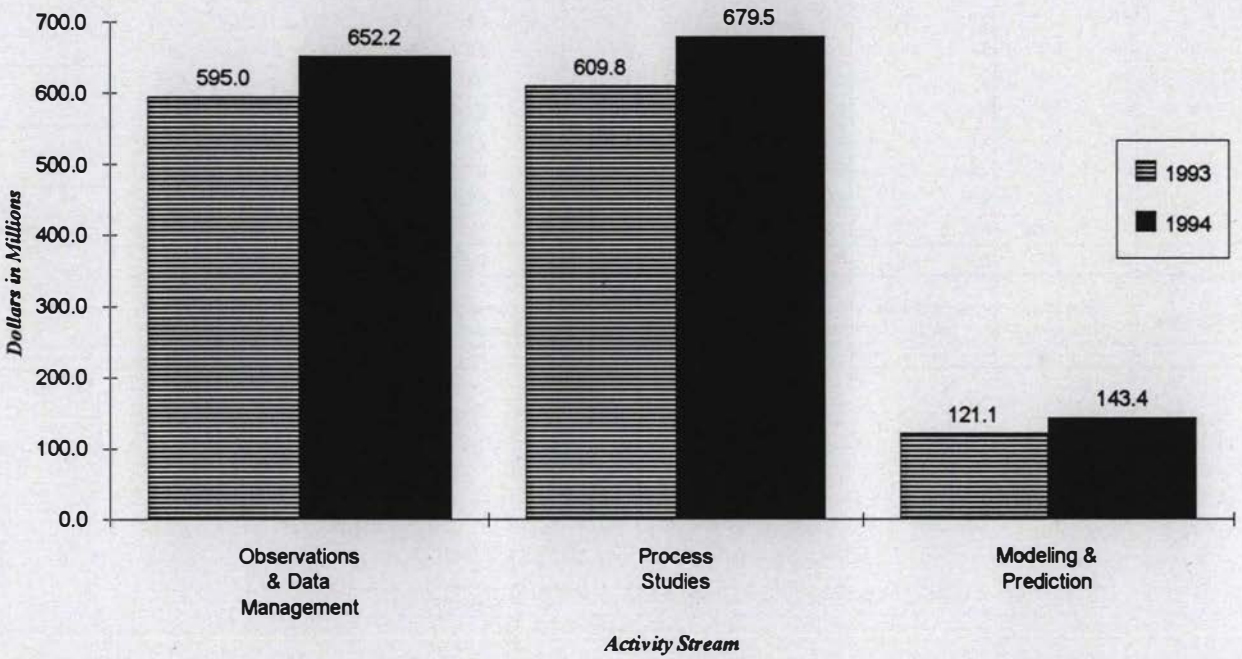


Table 2
FY 1993-1994 U.S. Global Change Research Program
Focused Budget by Science Element
(Dollars in Millions)

	Total Budget		Climate & Hydrologic Systems		Biogeochemical Dynamics		Ecological Systems & Dynamics		Earth System History		Human Interactions		Solid Earth Processes		Solar Influences	
	1993	1994	1993	1994	1993	1994	1993	1994	1993	1994	1993	1994	1993	1994	1993	1994
Agency Totals	1,326.0	1,475.1	595.9	663.9	340.7	376.2	224.3	249.3	20.2	24.7	22.2	24.4	108.1	117.3	14.8	19.3
DOC/NOAA	66.9	89.9	49.0	52.0	11.2	11.2	3.0	3.0	3.0	3.0	0.8	0.8	0.0	0.0	0.1	0.1
DOD	6.6	6.8	4.0	4.2	1.1	1.0	1.0	1.0	0.2	0.3	0.0	0.0	0.3	0.3	0.0	0.0
DOE	89.3	98.3	68.4	77.0	14.5	15.0	3.9	3.8	0.0	0.0	2.5	2.5	0.0	0.0	0.0	0.0
DOI	37.7	34.0	11.9	10.3	2.3	3.0	7.9	8.0	8.0	7.9	2.8	1.4	4.8	3.4	0.0	0.0
EPA	25.8	27.5	0.0	0.3	13.0	13.7	9.4	10.7	0.1	0.2	3.3	2.8	0.0	0.0	0.0	0.0
HHS	1.2	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	1.5	0.0	0.0	0.0	0.0
NASA	921.1	1,013.1	418.0	459.9	254.9	280.3	148.7	163.5	0.0	0.0	0.0	0.0	91.7	100.9	7.8	8.5
NSF	124.0	189.0	40.5	56.1	30.0	38.4	21.4	29.9	7.8	12.2	9.3	13.0	10.4	11.8	4.8	7.8
Smithsonian	7.3	7.3	0.0	0.0	0.4	0.4	4.5	4.5	0.7	0.7	0.7	0.7	0.9	0.9	0.1	0.1
TVA	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
USDA	48.0	47.6	4.0	4.0	13.3	13.2	24.5	24.9	0.4	0.4	1.8	2.1	0.0	0.0	2.0	3.0

Figure 4
U.S. Global Change Research Program
Focused Budget by Science Element

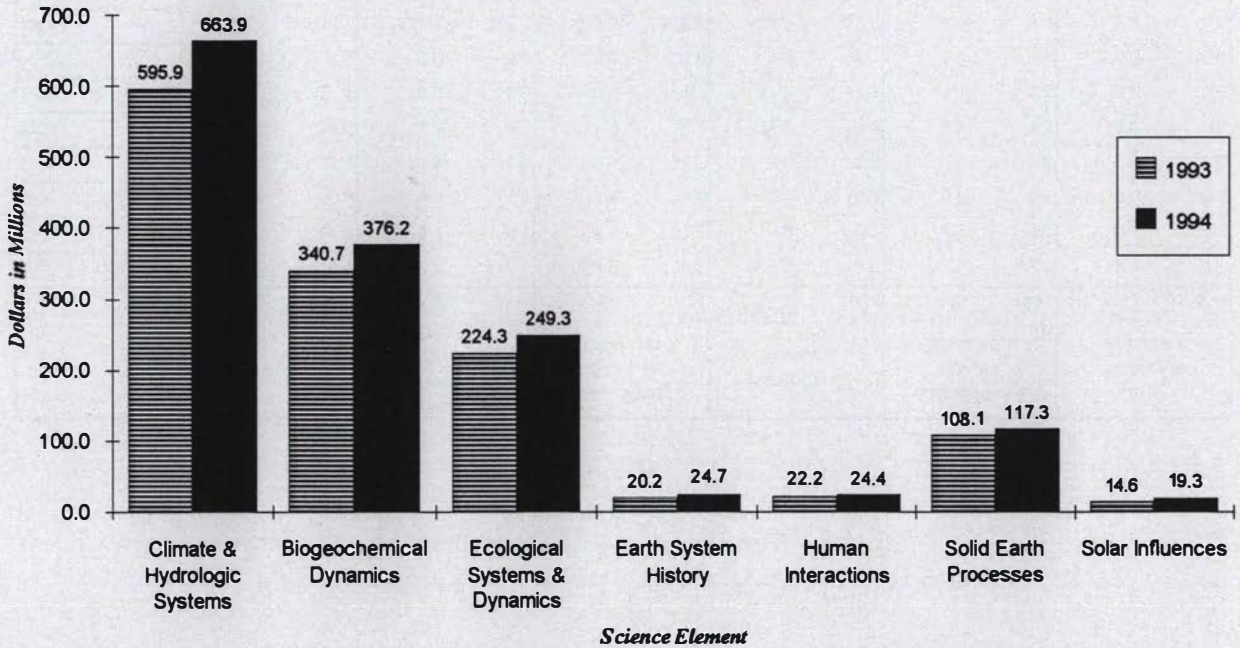


Table 3
FY 1993-1994 U.S. Global Change Research Program
Focused Budget by Integrating Theme
(Dollars in Millions)

	Total Budget		Greenhouse Gases, Aerosols & Ozone		Water, Energy & Sea Level Changes		Ecological Studies		Economics & Human Influences		Other Research Activities	
	1993	1994	1993	1994	1993	1994	1993	1994	1993	1994	1993	1994
Agency Totals	1,326.0	1,475.1	402.4	442.9	659.9	736.0	225.1	249.0	19.3	22.1	19.3	25.1
DOC/NOAA	66.9	69.9	8.7	8.7	54.5	57.5	3.0	3.0	0.6	0.6	0.1	0.1
DOD	6.6	6.8	1.3	1.5	4.6	4.6	0.7	0.7	0.0	0.0	0.0	0.0
DOE	89.3	98.3	13.8	14.0	69.1	78.0	3.9	3.8	2.5	2.5	0.0	0.0
DOI	37.7	34.0	3.8	3.9	18.9	16.2	12.2	12.6	2.8	1.3	0.0	0.0
EPA	25.8	27.5	13.0	12.6	0.5	1.7	11.3	12.2	0.4	0.4	0.6	0.6
HHS	1.2	1.5	0.0	0.0	0.0	0.0	0.0	0.0	1.2	1.5	0.0	0.0
NASA	921.1	1,013.1	322.4	354.5	460.5	506.6	138.2	152.0	0.0	0.0	0.0	0.0
NSF	124.0	169.0	30.0	38.4	45.1	63.7	21.4	29.9	9.3	13.0	18.2	24.0
Smithsonian	7.3	7.3	0.8	0.8	0.6	0.6	5.2	5.2	0.7	0.7	0.0	0.0
TVA	0.1	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
USDA	46.0	47.6	8.6	8.5	6.0	7.0	29.2	29.6	1.8	2.1	0.4	0.4

Figure 5
U.S. Global Change Research Program
Focused Budget by Integrating Theme

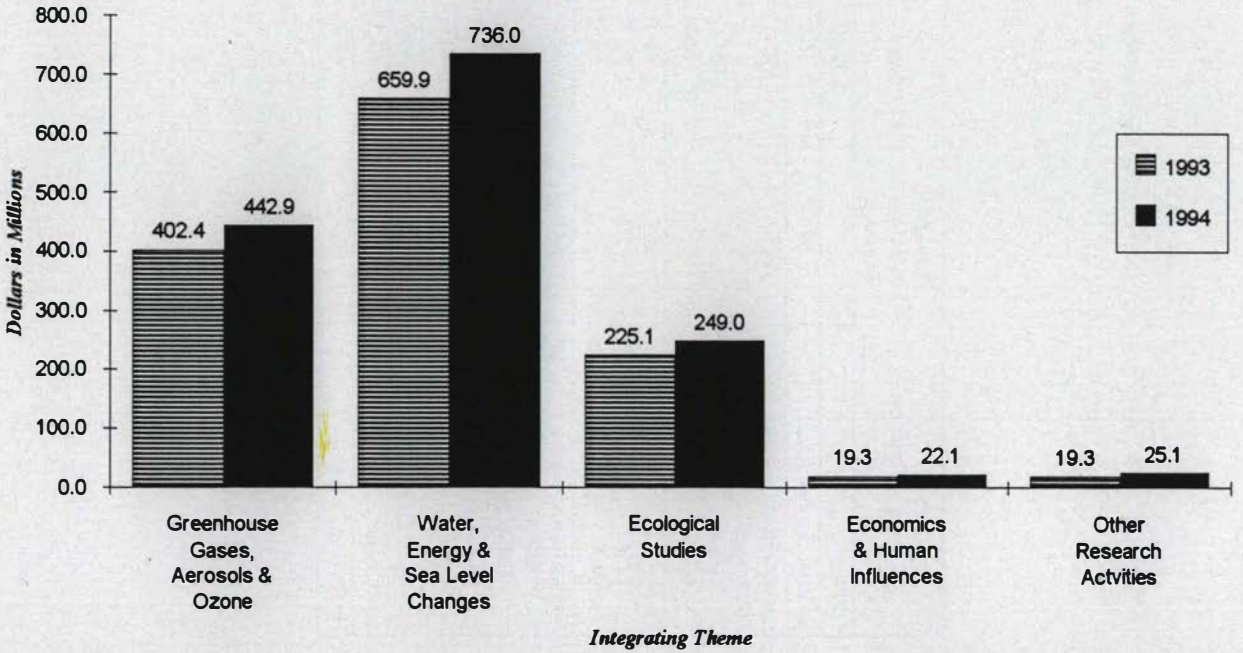
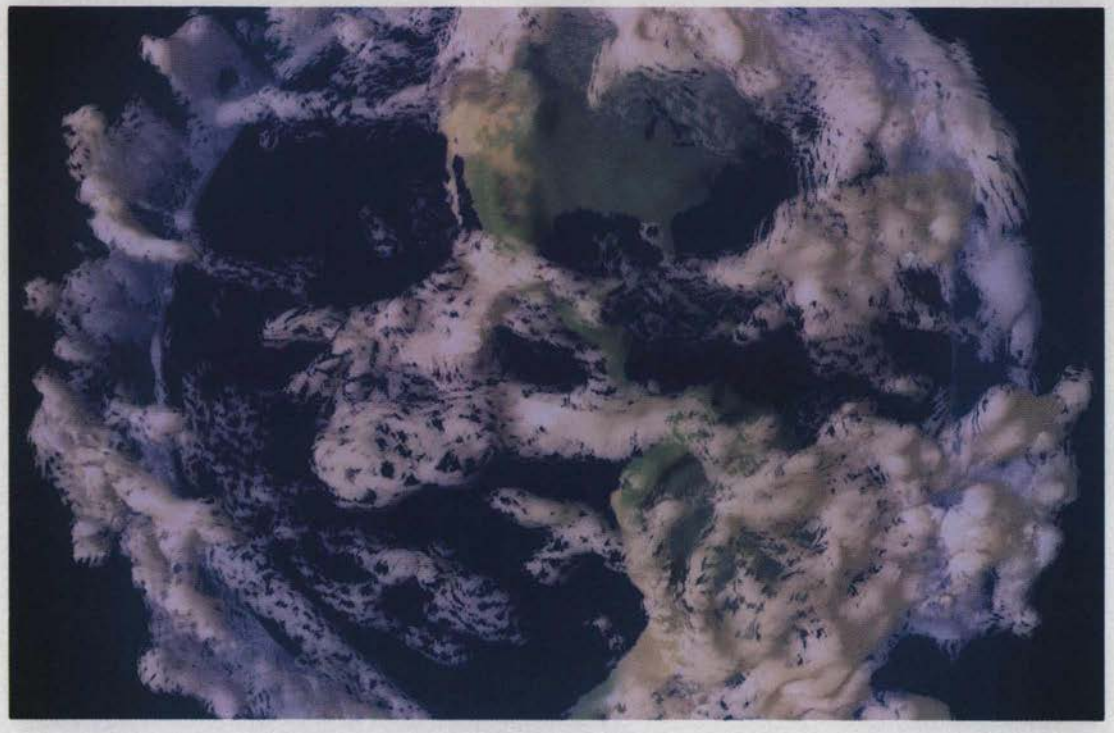


Table 4
FY 1993-1994 U.S. Global Change Research Program Focused Budget by Budget Function (Dollars in Millions)

Budget Function	Budget Function Number	1993 Budget	1994 Budget
TOTAL		1,326.0	1,475.1
National Defense (DOD)	50	6.6	6.8
General Science, Space & Technology	250	1,045.1	1,182.1
NASA		921.1	1,013.1
NSF		124.0	169.0
Energy	270	89.4	98.4
DOE		89.3	98.3
TVA		0.1	0.1
Natural Resources & Environment	300	130.4	131.4
DOC/NOAA		66.9	69.9
DOI		37.7	34.0
EPA		25.8	27.5
Agriculture (USDA)	350	46.0	47.6
Smithsonian	503	7.3	7.3
Health (HHS/NIEHS)	550	1.2	1.5

Global Cloudiness

Graphical representation of the instantaneous global cloudiness during a hypothetical January day, as simulated by a model which is part of a cooperative international program with the European Centre for Medium Range Weather Forecasts (ECMWF). The graphical display was developed cooperatively with the High Performance Computing and Communication (HPCC) Program. The vertical dimension is exaggerated to distinguish high and low clouds, and the texture of the clouds provides an indication of wind speed. (Graphic courtesy of Lawrence Livermore National Laboratory and ECMWF.)



VI. Linkages to the Clinton/Gore Science and Technology Program and Other FCCSET Initiatives

In the February 22, 1993 report entitled *Technology for America's Economic Growth, A New Direction to Build Economic Strength*, President Clinton and Vice-President Gore describe a strategy for moving America's investments in science and technology in a "...new direction to build economic strength and spur economic growth." The U.S. Global Change Research Program is an important element of this strategy. The February 22 report identifies the importance of investments in research to better understand global warming, ozone depletion, and other phenomena important to local, regional, and global environments and notes that "This research is essential if we are to fully assess the damage mankind is doing to the planet and take effective action to address it." Since its inception, the U.S. Global Change Research Program has been implemented as both a source of sound scientific information to support national and international decisionmaking and as a focus for multinational collaboration in the development and application of new scientific insights and technological advancements to practical problems of economic development and environmental stewardship.

Math and Science Education

In its January 1993 report entitled *Pathways to Excellence: A Federal Strategy for Science, Mathematics, Engineering, and Technology Education*, the FCCSET Committee on Education and Human Resources (CEHR) notes that, in the Nation's educational goals:

> "Mathematics and science education receives special emphasis in this reform agenda because of its centrality in the education process; and because science and technology have a profound effect on our Nation's economic competitiveness and on the quality of life of its citizens."

Like the CEES, the CEHR provides the interagency framework to guide the development and implementation of an integrated, coordinated, multi-year Federal effort in mathematics, engineering, and technology education. In this context, the CEHR has established a planning framework with the following Strategic Objectives:

- Improved science and mathematics performance;
- Strong elementary and secondary teacher work force;
- Adequate pipeline for science and technology work force, including greater participation of individuals under-represented in science, mathematics, engineering, and technology education; and
- Improved public science literacy.

With these overall objectives in mind, the CEES agencies have developed complementary USGCRP education efforts designed to: (i) develop an informed and literate public able to utilize the results of scientific research and make wise resource-use choices, and; (ii) encourage the training of future scientists in multi-disciplinary approaches to study global change over the next decade. To accomplish these tasks, the CEES agencies are pursuing a coordinated program of global change education activities that will provide multi-disciplinary opportunities at all grade levels (from K-12 through college and graduate school) and informal continuing and public education.

High Performance Computing and Communications

The High Performance Computing and Communications (HPCC) Program, coordinated by the FCCSET Subcommittee on High

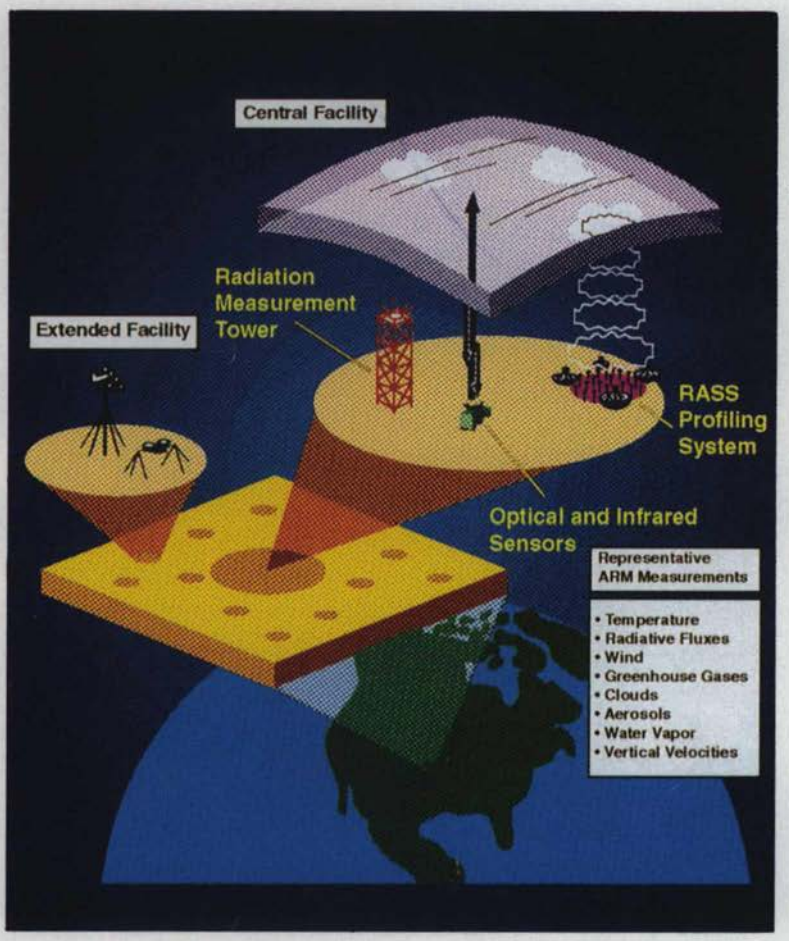
Performance Computing, Communications, and Information Technology, is dedicated to extending U.S. technological leadership in high performance computing and networking, and to speed the pace of innovations in these areas to serve the national economy and the global environment.

There are natural connections between the activities of the HPCC Program and those of the CEES U.S. Global Change Research Program, particularly in the areas of climate modeling—one of the HPCC "Grand Challenge" areas—and environmental modeling and prediction—one of the key long-term HPCC application areas.

Joint activities of the USGCRP Integrative Modeling and Prediction (IMAP) Working Group and the HPCC Science and Engineering Computing Working Group include coordination efforts for the mutual benefit of both programs, particularly in the area of parallel computation and high speed communication of global change data.

High resolution USGCRP climate models have been improved through implementation of parallel algorithms and operation on parallel computers, including new massively-parallel architectures. Coupled ocean-atmosphere models are to be run on distributed supercomputer networks, and their results distributed via the networks, representing a substantial workload for the evolving National Research and Education Network (NREN) project of the HPCC.

Use of NREN, which will provide dramatically improved data transmission speeds (Gbit/sec) and connectivity, will support substantial improvements in global change modeling. Remote access for researchers and high-quality interactive graphics capabilities for visualizing the results of global change modeling will become more readily available. Advanced networks will facilitate access to data for model verification and testing, as well as encourage research collaboration.



ARM Site

The Atmospheric Radiation Measurement (ARM) program deployed the first of five planned Cloud and Radiation Testbed (CART) sites. ARM is a major program of atmospheric measurement and modeling intended to improve the understanding of the processes and properties that affect atmospheric radiation, with a particular focus on the influence of clouds and the role of cloud radiative feedback. (Graphic courtesy of the U.S. Department of Energy.)

VII. Appendix: Fiscal Year 1993-1994 USGCRP Budget by Project

(Dollars in Millions)

The allocation of resources by project reflected in this table are estimates only and are subject to change based on discussions of scientific and programmatic priorities among CEES agencies, their individual advisory mechanisms, and the broad national and international scientific communities.

AGENCY	BUREAU	PROJECT	FY93	FY94
DOC	NOAA	Long-term Ocean Observations	6.9	6.9
DOC	NOAA	Operational Measurements	4.3	4.3
DOC	NOAA	Measurement Technique Development	0.3	0.3
DOC	NOAA	Information Management	4.2	4.2
DOC	NOAA	Tropical Oceans/Global Atmosphere (TOGA)	8.0	8.0
DOC	NOAA	Clouds, Energy, Water (GEWEX)	4.2	4.2
DOC	NOAA	Ocean Circulation/Biogeochemistry	12.7	12.7
DOC	NOAA	Climate Modeling and Analysis	12.1	15.1
DOC	NOAA	Atmospheric Chemistry	7.5	7.5
DOC	NOAA	Marine Ecosystem Response	3.0	3.0
DOC	NOAA	Paleoclimate	3.0	3.0
DOC	NOAA	Economics Research	0.6	0.6
DOC	NOAA	Solar Variability	0.1	0.1
DOC		TOTAL	66.9	69.9
DOD	ONR	High Latitude Dynamics-Arctic Sediment	0.2	0.3
DOD	ONR	Ocean Measurements	0.6	1.1
DOD	ONR	Ocean Ecological Dynamics	1.0	1.0
DOD	ONR	Boundary Layer Dynamics	1.1	1.0
DOD	CRREL	Regional Resolving Models	0.2	0.3
DOD	ONR	High Latitude Dynamics-Arctic Lead	2.2	1.5
DOD	CRREL	High Latitude Dynamics-Impacts	0.3	0.3
DOD	ONR	Regional Resolving Models	1.0	1.3
DOD		TOTAL	6.6	6.8

AGENCY	BUREAU	PROJECT	FY93	FY94
DOE	OHER	Core CO_2 Research	19.1	17.6
DOE	OHER	CHAMMP - Computer Hardware, Advanced Math & Model Physics	11.4	11.9
DOE	OHER	National Institute for Global Environmental Change	10.9	9.6
DOE	OHER	Oceans Research	5.1	5.4
DOE	OHER	Quantitative Links	5.1	5.3
DOE	OHER	ARM - Atmospheric Radiation Measurements	31.1	40.6
DOE	OHER	Education	2.8	2.9
DOE	OHER	Information/Coordination	2.2	2.3
DOE	OHER	Unmanned Aerospace Vehicles (UAVs)	0.0	1.0
DOE	OHER	Economics	1.6	1.7
DOE		TOTAL	89.3	98.3
DOI	USGS	Land Characterization	2.0	2.0
DOI	USGS	Land Data	5.4	5.4
DOI	USGS	Volcano Emissions	0.4	0.4
DOI	USGS	Cold Regions Research	1.4	1.4
DOI	USGS	Climates of Arid & Semi Arid Regions	0.9	0.9
DOI	USGS	Paleoclimates	7.7	7.6
DOI	USGS	Biogeochemical Exchanges	1.2	2.2
DOI	USGS	Coastal Erosion & Wetlands Processes	3.0	0.0
DOI	USGS	Sensitivity of Water Resources	1.0	0.0
DOI	USGS	Interaction of Climate & Hydrologic Systems	5.0	5.0
DOI	BIA	Uneven-Aged BIA Forests	0.1	0.1
DOI	BOR	Sensitivity of Hydrological Systems	1.1	0.0
DOI	BOR	Regional Studies	1.2	1.2
DOI	FWS	Coastal Wetland Change & Dynamics	1.1	1.1
DOI	FWS	Monitoring Fish & Wildlife Impacts	2.0	2.1
DOI	NPS	Integrated Studies of NPS Ecosystems	2.9	3.3
DOI	NPS	Dynamics of Coastal Systems	0.1	0.1
DOI	BLM	Ecological Change in Environmentally Stressed Ecosystems of the Western & Northern U.S.	1.1	1.1
DOI	BOM	Methane Emissions from Coal Seams	0.1	0.1
DOI		TOTAL	37.7	34.0
EPA	ORD	Anthropogenic Methane/RITG Emissions	4.0	4.0
EPA	ORD	Tropospheric Chemistry	3.1	3.1
EPA	ORD	Greenhouse Gas Pools & Fluxes in Terrestrial Ecosystems	1.8	2.3
EPA	ORD	Biospheric Carbon Pools & Fluxes	1.4	1.4
EPA	ORD	Climate-Induced Biospheric Feedbacks from Soils	0.8	0.8
EPA	ORD	Monitoring Forest Conversion/ Biomass Burning	1.4	1.4

AGENCY	BUREAU	PROJECT	FY93	FY94
EPA	ORD	Earth System Modeling Analysis	2.6	3.1
EPA	ORD	North American Landscape Characterization	2.1	2.1
EPA	ORD	Effects of Global Changes on Rice Yields	1.5	1.5
EPA	ORD	Micro- to Macro-Scale Eco. Responses	3.8	4.2
EPA	ORD	Stratospheric Ozone Depleting Chemicals	1.1	1.1
EPA	ORD	Early Detection of the Greenhouse Signature	0.0	1.0
EPA	ORD	UV-B Monitoring and Exposure Index	2.2	1.5
EPA		TOTAL	25.8	27.5
HHS	NIEHS	Human Health Effects of CFC Replacement Chemicals	0.5	0.5
HHS	NIEHS	Human Health Effects of Increased Exposure to Shorter Wavelength UV	0.7	1.0
HHS		TOTAL	1.2	1.5
NASA	MTPE	Earth Probes	99.4	97.3
NASA	MTPE	Payload & Instrument Development	35.4	22.9
NASA	MTPE	Earth Observing System (EOS)	263.8	322.7
NASA	MTPE	Space-based Subtotal	398.6	442.9
NASA	MTPE	Mission Operations & Data Analysis (incl. Landsat)	147.6	160.8
NASA	MTPE	EOS-Data Information Systems (EOSDIS)	130.7	182.7
NASA	MTPE	Research and Analysis	166.2	181.5
NASA	MTPE	Airborne Program	20.7	25.2
NASA	MTPE	Construction of Facilities	57.3	20.0
NASA	MTPE	Ground-based Subtotal	522.5	570.2
NASA		TOTAL	921.1	1013.1
NSF	GEO	ARCSS-Arctic System Science	13.3	16.0
NSF	GEO	CHP-Continental Hydrologic Processes	1.0	1.1
NSF	GEO	Geosystems Databases	1.3	2.0
NSF	GEO	ROCEW-Role of Clouds, Energy & Water	0.6	2.0
NSF	GEO	CMAP-Climate Modeling, Analysis & Prediction	2.0	6.0
NSF	GEO	TOGA-Tropical Oceans Global Atmosphere	14.7	16.1
NSF	GEO	WOCE-World Ocean Circulation Experiment	15.7	20.5

AGENCY	BUREAU	PROJECT	FY93	FY94
NSF	GEO	GTCP-Global Tropospheric Chemistry Program	11.5	14.7
NSF	GEO	JGOFS- Joint Global Ocean Flux Study	13.8	18.6
NSF	GEO	Antarctic Ecosystems	1.5	1.5
NSF	GEO	Ozone Depletion/UV Effects	5.6	5.6
NSF	BIO	EROC - Ecological Rates of Change	3.0	4.1
NSF	GEO	GLOBEC-Global Ocean Ecosystems Dynamics	3.8	8.2
NSF	BIO/GEO	LMER-Land-Margin Ecosystems Research	2.3	3.0
NSF	BIO	WEV-Water-Energy-Vegetation	4.9	5.8
NSF	GEO	Abrupt Climate Change	0.1	0.9
NSF	GEO	Geological Record of Global Change	2.9	4.7
NSF	GEO	MESH-Marine Aspects of Earth System History	0.3	2.0
NSF	SBE	Human Dimensions of Global Change	4.2	5.4
NSF	SBE	Economics Research on Global Change	4.6	6.4
NSF	GEO	Geodynamics	6.2	7.5
NSF	GEO	RIDGE-Ridge Interdisciplinary Global Experiment	4.1	4.1
NSF	GEO	CEDAR-Coupling, Energetics, & Dynamics of Atmospheric Regions	4.4	5.3
NSF	GEO	GEM-Geospace Environment Monitoring	0.2	1.4
NSF	GEO	SunRISE-Radiative Inputs of the Sun to Earth	0.0	0.9
NSF	GEO/BIO	Global Change Education & Training	0.0	0.2
NSF	GEO/BIO	Regional Research Institutes	2.0	5.0
NSF		TOTAL	124.0	169.0
SI	NMNH	Tropical Biological Diversity Program	1.2	1.2
SI	NMNH	Tropical Coastal Ecosystems Program	0.4	0.4
SI	NMNH	Human Ecology History	0.3	0.3
SI	NMNH	Nile Delta Subsidence & Sea Level Rise	0.1	0.1
SI	NMNH	Global Volcanism Program	0.4	0.4
SI	NMNH	Paleoecological Effects of Climate Change	1.1	1.1
SI	STRI	Tropical Forest Science Program	0.9	0.9
SI	STRI	Patterns of Change in East African Savanna Ecosystems	0.0	0.0
SI	STRI	Tropical Agroforestry Program	0.2	0.2
SI	SERC	Chesapeake Bay Global Change Research	0.6	0.6
SI	SERC	Temperate & Tropical Forest Canopy Biology	0.4	0.4
SI	SAO	Atmospheric Physics and Chemistry	0.2	0.2
SI	SAO	Solar Studies/Global Change	0.1	0.1
SI	SAO	Space Geodetic Sea Level Monitoring		
SI	NASM	Global Change in Earth's Drylands	0.3	0.3
SI	IC	SI/MAB Biological Diversity Program	0.1	0.1

AGENCY	BUREAU	PROJECT	FY93	FY94
SI	NZP	Predicting Species Responses	0.6	0.6
SI	NZP	Migratory Birds	0.3	0.3
SMITHSONIAN		TOTAL	7.3	7.3
TVA	RBO	Regional Climate Impact Assessment	0.1	0.1
TVA		TOTAL	0.1	0.1
USDA	ARS	Scale Effect of Hydro. Proc.	1.6	1.6
USDA	ARS	Biogeochemical Fluxes	3.0	3.1
USDA	ARS	Ecosystem Modeling	3.2	3.2
USDA	ARS	Pred. Impact on Sustain. Wtr	2.2	2.2
USDA	FS	Ecological System Dynamics	10.5	10.4
USDA	FS	Atmosphere/Biosphere Gas & Energy Exchange	7.5	7.4
USDA	FS	Disturbance Ecology	3.3	3.2
USDA	FS	Integrating Human Activities & Natural Resources	1.0	1.3
USDA	ERS	Econ. Sys. & Global Change	0.8	0.8
USDA	CSRS	Global Change Research	9.4	9.9
USDA	CSRS	UV-B Network	2.0	3.0
USDA	SCS	Climate Information	0.2	0.2
USDA	SCS	Soil Carbon/Soil Genesis	0.9	0.9
USDA	SCS	Soil Landscape Model	0.4	0.4
USDA		TOTAL	46.0	47.6
USGCRP		TOTAL	$ 1,326.0	$1,475.1

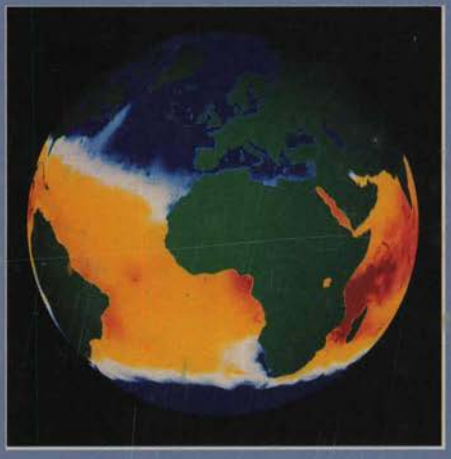
Agency Acronyms

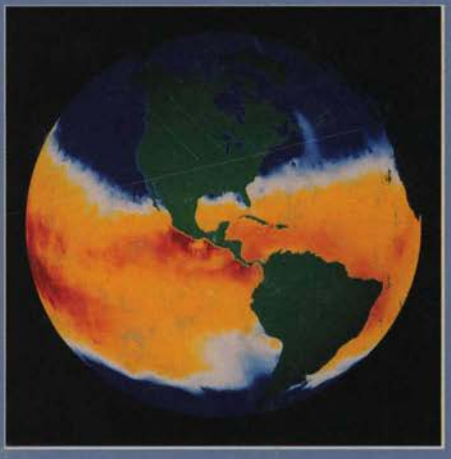
DOC	NOAA	National Oceanic and Atmospheric Administration
DOD	CRREL	Cold Regions Research and Engineering Laboratory
	ONR	Office of Naval Research
DOE	OHER	Office of Health & Environmental Research
DOI	BIA	Bureau of Indian Affairs
	BLM	Bureau of Land Management
	BOM	Bureau of Mines
	BOR	Bureau of Reclamation
	FWS	Fish & Wildlife Service
	NPS	National Park Service
	OS	Office of the Secretary
	USGS	U.S. Geological Survey
EPA	ORD	Office of Research & Development
HHS	NIEHS	National Institute of Environmental Health Sciences
NASA	MTPE	Mission to Planet Earth
NSF	BIO	Directorate for Biological Sciences
	GEO	Directorate for Geosciences
	SBE	Directorate for Social, Behavioral, and Economic Sciences
SI	IC	International Center
	NASM	National Air and Space Museum
	NMNH	Natural Museum of Natural History
	NZP	National Zoological Park
	SAO	Smithsonian Astrophysical Observatory
	SERC	Smithsonian Environmental Research Center
	STRI	Smithsonian Tropical Research Institute
TVA	RBO	River Basin Operations
USDA	ARS	Agricultural Research Service
	CSRS	Cooperative State Research Service
	ERS	Economic Research Service
	FS	Forest Service
	SCS	Soil Conservation Service

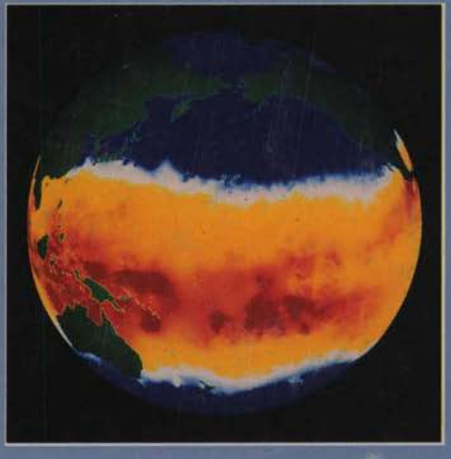
These four images show the temperature of the world's oceans during the first week of 1992. The false color images show the temperature of the sea surface as measured by the Advanced Very High Resolution Radiometer (AVHRR) instrument that is on board NOAA's polar orbiter, a satellite which provides observational coverage of the Earth. The polar orbiter measures other environmental properties, including land surface temperature, ozone concentration, humidity, snow and cloud cover, sea-ice distribution, vegetative cover, and desertification.

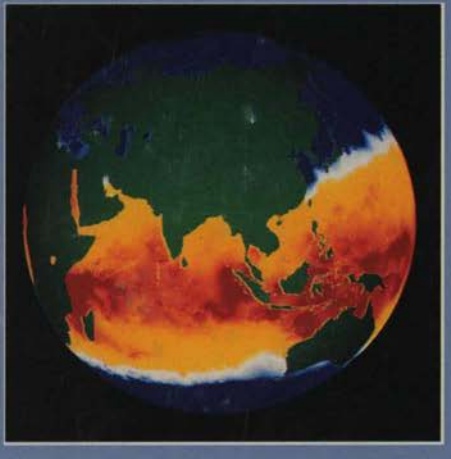
The sea surface temperatures range from blue (cold) through yellow and red (warm). (Courtesy of NOAA.)

The U.S. Global Change Research Program









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