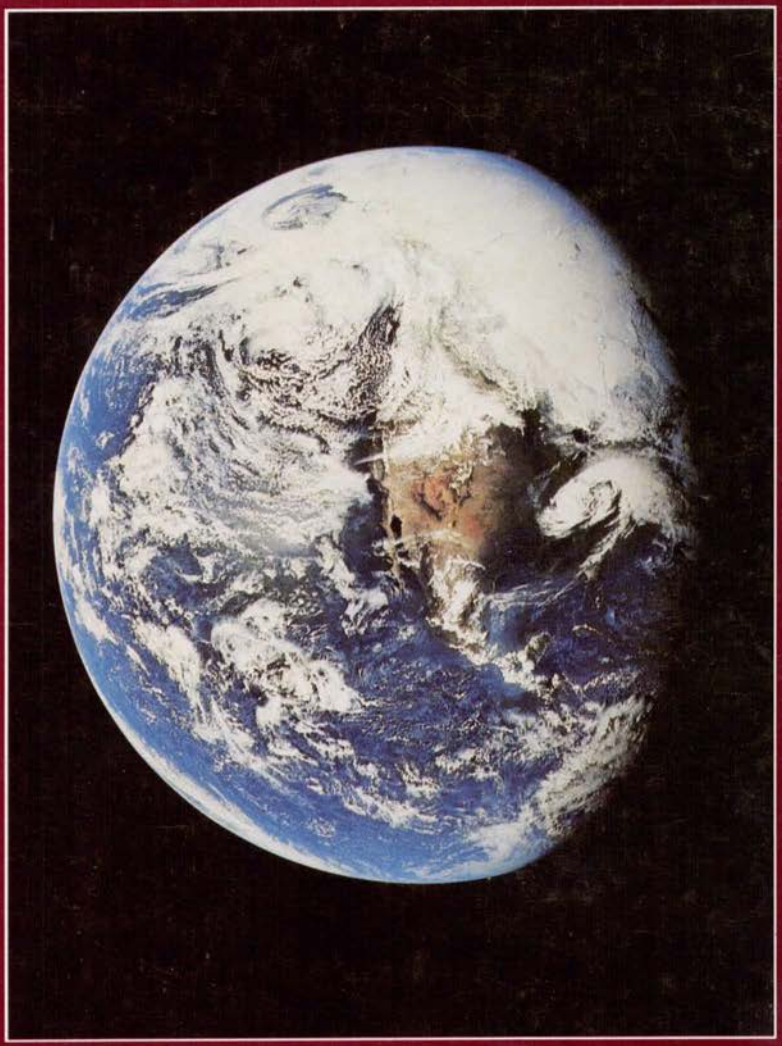
Our Changing Planet:

The FY 1993
U.S. Global Change Research Program



A Report by the
Committee on Earth and Environmental Sciences

A Supplement to the
U.S. President's Fiscal Year 1993 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.

Our Changing Planet:

The FY 1993

U.S. Global Change Research Program

A Report by the
Committee on Earth and Environmental Sciences

A Supplement to the
U.S. President's Fiscal Year 1993 Budget

Our Changing Planet: The FY 1993 U.S. Global Change Research Program has been printed on recycled paper.

To obtain a copy of this document send request to:

Committee on Earth and Environmental Sciences
c/o National Science Foundation
Attn: Forms and Publications
1800 G Street NW, Room 232
Washington, DC 20550
(202) 357-7861

Office of Science and Technology Policy
Federal Coordinating Council for Science, Engineering and Technology (FCCSET)

Committee on Earth and Environmental Sciences

Chairman

Dallas L. Peck, Department of the Interior, United States Geological Survey

Vice-Chairmen

Erich W. Bretthauer, Environmental Protection Agency
Lennard A. Fisk, National Aeronautics and Space Administration

Members

Robert E. Grady, Office of Management and Budget
Nancy Maynard, Office of Science and Technology Policy
E. U. Curtis Bohlen, Department of State
Dominic J. Monetta, Department of Defense
Harlan L. Watson, Department of the Interior
Harry C. Mussman, United States Department of Agriculture
John A. Knauss, Department of Commerce
William Roper, Department of Health and Human Services
G. Robert Fuller, Department of Housing and Urban Development
Joseph F. Canny, Department of Transportation
David J. Galas, Department of Energy
Harold R. Denton, Nuclear Regulatory Commission
Walter E. Massey, National Science Foundation
Michael R. Deland, Council on Environmental Quality
Robert Hoffman, Smithsonian Institution
W. F. Willis, Tennessee Valley Authority
Kenneth Olden, National Institute of Environmental Health Services
Fred E. Springer, Federal Energy Regulatory Commission
Grant C. Peterson, Federal Emergency Management Agency

Executive Secretary

Paul V. Dresler, Department of the Interior, United States Geological Survey
Hannah E. Sluss, CEES Secretary

FCCSET Directorate

Vicki V. Sutton, Executive Director
Ralph P. Brescia, Senior Policy Analyst

Office of Science and Technology Policy
Federal Coordinating Council For Science, Engineering and Technology (FCCSET)
Committee on Earth and Environmental Sciences

Subcommittee on Global Change Research

Chairman

Robert W. Corell, National Science Foundation

Vice-Chairman

J. Michael Hall, Department of Commerce, National Oceanic and Atmospheric Administration

Members

Jack D. Fellows, Office of Management and Budget
Nancy G. Maynard, Office of Science and Technology Policy
Fred E. Saalfeld, Department of Defense
Aristides Patrinos, Department of Energy
Mary Martin Gant, Department of Health and Human Services, National Institute of Environmental Health Sciences
Stephen E. Ragone, Department of the Interior
William L. Sullivan, Department of State
Courtney Riordan, Environmental Protection Agency
Shelby G. Tilford, National Aeronautics and Space Administration
Daniel E. Appleman, Smithsonian Institution
Norris A. Nielsen, Tennessee Valley Authority
Gary R. Evans, United States Department of Agriculture

Executive Secretary

Hassan Virji, National Science Foundation
Michael W. Patterson, Department of Commerce, National Oceanic and Atmospheric Administration
Susan C. Henson, Secretary

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C 20506

MEMBERS OF CONGRESS:

I am pleased to forward with this letter "Our Changing Planet: The FY 1993 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 1993 Budget. This is the fourth report in a series established in 1989.

This report outlines a Presidential 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. Because of the importance of this area, even in a time of substantial fiscal constraints, the President is proposing a 24 percent increase in the budget for this effort in FY 1993.

The U.S. Global Change Research Program is a key component of the President's overall approach to the U.S. responsibility for global stewardship. This broad approach recognizes the profound economic and social implications of responding to global environmental changes and maintains U.S. leadership on this issue. Given the international importance of negotiations on the Framework Convention on Climate Change, the report emphasizes activities intended to respond to scientific uncertainties identified through the assessment process of the Intergovernmental Panel on Climate Change (IPCC).

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. The report has benefited from close interaction with the National Academy of Sciences, the International Council of Scientific Unions' International Geosphere-Biosphere Programme, and the World Meteorological Organization's World Climate Research Programme. As such, I believe 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 want to take this opportunity to salute the superb leadership of Dr. Dallas Peck, who has been Chairman of the Committee on Earth and Environmental Sciences since it was established. He and Dr. Robert Corell, Chairman of the CEES Working Group on Global Change, have led the coordination and integration of the interagency strategy for this Initiative over the course of several years. They and their interagency committee members, associates, and staff are all to be commended for the excellent work that is manifest in both the Initiative and the report.

In the near future, Dr. Frederick Bernthal will succeed Dr. Peck as the Chairman of the Committee on Earth and Environmental Sciences. I am certain that he will continue the tradition begun by Dr. Peck in working with CEES to make the United States the world leader in global change research.

D. Allan Bromley
Director

Table of Contents

Executive Summary 1

Overview 3

Recent Research Progress Toward USGCRP Objectives 8

The FY 1993 Program 24

Research Program and Budget 28

- Budget by Integrating Themes 28
  - Climate Modeling and Prediction 28
  - Global Water and Energy Cycles 31
  - Global Carbon Cycle 34
  - Ecological Systems and Population Dynamics 39
- Budget for Economics Research Related to Global Change 44
- Budget by Science Element 49
- Budget by Scientific Objective 49
- Budget by Agency 49
- Budget by Federal Budget Function 59

Areas Needing Special Emphasis 61

- Data and Information Management 61
- Space-Based Research 64
- International Dimensions 68
- Program Management and Evaluation 70
- Remotely Piloted Aircraft 71

Appendix 73

List of Tables and Figures

Tables

1. FY 1992-1993 U.S. Global Change Research Program Focused Budget by Integrating Theme..... 29

2. FY 1990-1993 Focused Budget for Economics Research Related to Global Change..... 48

3. FY 1990-1993 Contributory Budget for Economics Research Related to Global Change..... 48

4. FY 1992-1993 U.S. Global Change Research Program Focused Budget by Science Element..... 50

5. FY 1992-1993 U.S. Global Change Research Program Focused Budget by Scientific Objective..... 52

6. FY 1992-1993 Budget of Contributory Programs to the U.S. Global Change Research Program..... 55

7. FY 1992-1993 U.S. Global Change Research Program Budget by Budget Function..... 60

Figures

1. U.S. Global Change Research Program Priority Framework..... 6

2. U.S. Global Change Research Program Budget by Integrating Theme..... 30

3. U.S. Global Change Research Program Budget by Science Element..... 51

4. U.S. Global Change Research Program Budget by Scientific Objective..... 53

5. U.S. Global Change Research Program Budget by Agency.... 54

Executive Summary

- World leaders continue to debate the economic and social implications of global environmental changes, both natural and human-induced.

- An improved predictive understanding of the integrated Earth system, including human interactions, will provide direct benefits by anticipating and planning for possible impacts on commerce, agriculture, energy, resource utilization, human safety, and environmental quality.

- The central goal of the U.S. Global Change Research Program (USGCRP) is to help establish the scientific understanding and the basis for national and international policymaking related to natural and human-induced changes in the global Earth system by

  - establishing an integrated, comprehensive, long-term program of documenting the Earth system on a global scale;

  - conducting a program of focused studies to improve our understanding of the physical, geological, chemical, biological, and social processes that influence Earth system processes; and

  - developing integrated conceptual and predictive Earth system models.

- The highest priority near-term scientific and policy-related issue for the USGCRP is whether, and to what extent, human activities are changing, or will change, the global climate system.

- The President's FY 1993 Budget requests $1,372.4 million for the USGCRP. This represents an increase of $262.6 million, or 24 percent, over the FY 1992 level.

- Responding to the most critical scientific uncertainties identified by the Scientific and Impacts Working Groups of the Intergovernmental Panel on Climate Change (IPCC) as the highest priority near-term foci, the FY 1993 USGCRP continues the strategy of using the following four high-priority integrating themes:

- Climate Modeling and Prediction
- Global Water and Energy Cycles
- Global Carbon Cycle
- Ecological Systems and Population Dynamics

In addition, the USGCRP continues to support economics research related to global change.

- The FY 1993 USGCRP reflects a restructured Earth Observing System (EOS) consistent with the recommendations of the EOS Engineering Review Committee and includes a small satellite and remotely piloted aircraft effort supported by the CEES agencies.

- The USGCRP also continues support for investigations in stratospheric ozone, human interactions, solid Earth processes, and solar influences.

- The USGCRP has been developed by the Committee on Earth and Environmental Sciences (CEES) of the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET). It has been established in cooperation with the U.S. and international scientific communities through the National Academy of Sciences (NAS) and the International Council of Scientific Unions (ICSU), and is linked internationally to other government agencies, to the relevant intergovernmental organizations of the United Nations, and to other governmental and non-governmental organizations.

Overview

Background

The USGCRP has been developed by the interagency Committee on Earth and Environmental Sciences (CEES) of the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET). The USGCRP was established as a Presidential initiative in the FY 1990 Budget to help develop sound national and international policies related to global environmental issues, particularly global climate change.

The U.S. Global Change Research Program (USGCRP) was conceived and developed to be policy-relevant, and hence, to support the needs of the United States and other nations to address significant uncertainties in knowledge concerning the natural and human-induced changes now occurring in the Earth's life-sustaining environmental envelope.

The USGCRP is implemented through a priority-driven scientific research agenda that is designed to be integrated, comprehensive, and multidisciplinary. This comprehensive "Earth system science" approach provides the greatest potential of yielding timely and insightful understanding of the uncertainties in knowledge of both global- and regional-scale changes in the Earth's environment. It is designed explicitly to address scientific uncertainties in such areas as climate change, ozone depletion, changes in terrestrial and marine productivity, global water and energy cycles, sea level changes, the impact of global changes on human health and activities, and the impact of anthropogenic activities on the Earth system.

The USGCRP focuses in the near-term on the scientific uncertainties identified in the assessment process of the Intergovernmental Panel on Climate Change (IPCC) as well as the research needs identified by the International Geosphere-Biosphere Programme (IGBP) and the World Climate Research Programme (WCRP). The USGCRP seeks to address the implications of environmental changes, through both domestic and international forums such as the IPCC, the Montreal Protocol (for chlorofluorocarbons), the International Negotiating Committee (INC) for a Framework Convention on Climate Change, the United Nations Conference on Environment and Development (UNCED) which plans to develop an interna-

tional environmental action agenda, and a host of other important but lesser known activities.

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

- **Documenting Global Change (Observations)** through the establishment of an integrated, comprehensive, long-term program of observing and analyzing Earth system change on a global scale;

- **Enhancing Understanding of Key Processes (Process Research)** through a program of focused studies to improve our knowledge of the physical, geological, chemical, biological, and social processes that influence and govern Earth system behavior; and

- **Predicting Global and Regional Environmental Change (Integrated Modeling and Prediction)** through the development and application of integrated conceptual and predictive Earth system models.

The comprehensive nature of the USGCRP promises not only the availability of information to respond to today's policy questions but the maintenance of a strong foundation of multidisciplinary science required to support the unanticipated problems of tomorrow. The Antarctic ozone hole is a clear example of the significance of such Earth system "surprises". The rapid resolution of uncertainties and the subsequent development of an effective international policy response to ozone depletion demonstrates the value of a strong scientific foundation and a focused program of research.

The structure of the USGCRP draws upon the strengths of existing, fundamental disciplines to develop the interdisciplinary scientific approaches that an integrated global change research program demands. The Program's seven science elements (Figure 1) reflect the integrated and interdisciplinary nature of such a complex research effort. The ultimate success of the USGCRP requires progress in all seven scientific elements, as well as the development of data and information management systems necessary for analysis of integrated data sets.

Central to this strategy is a balance between ground- and space-based research activities. *In situ* and theoretical studies of physical, chemical, biological and geological processes will be complemented by a comprehensive space-based program to provide global observations of key environmental parameters. The U.S. and other nations are planning a comprehensive series of satellite launches, including intermediate and small satellites, through the coming decade to provide these global long-term observations, with a full-scale Earth Observing System (EOS) beginning operation by 1998.

Within its priority framework (Figure 1), the CEES evaluates proposed projects on the basis of (1) relevance and contribution to the overall USGCRP goal and objectives; (2) scientific merit as documented by peer review; (3) readiness for implementation and likelihood of early results; (4) linkages to other national and international programs; (5) costs in the short- and long-term; (6) agency approval for inclusion in the USGCRP. Existing high priority programs will be adequately funded prior to initiating new efforts. The framework and the evaluation criteria are an essential part of the program and budget development strategy of the CEES. They provide the structure within which CEES evaluates and develops (1) the essential, high priority national and international components of the USGCRP in each fiscal year; and (2) the recommended budgets to support those critical components.

The USGCRP cooperates closely with the U.S. and international scientific communities, through the National Academy of Sciences (NAS) and the International Council of Scientific Unions (ICSU). The USGCRP is also linked internationally to intergovernmental organizations, such as the World Meteorological Organization (WMO), the United Nations Environment Programme (UNEP), the Intergovernmental Oceanographic Commission (IOC), and to a number of agencies of other governments through the informal International Group of Funding Agencies (IGFA) for Global Change Research, and space agencies through the Committee on Earth Observations Satellites (CEOS).

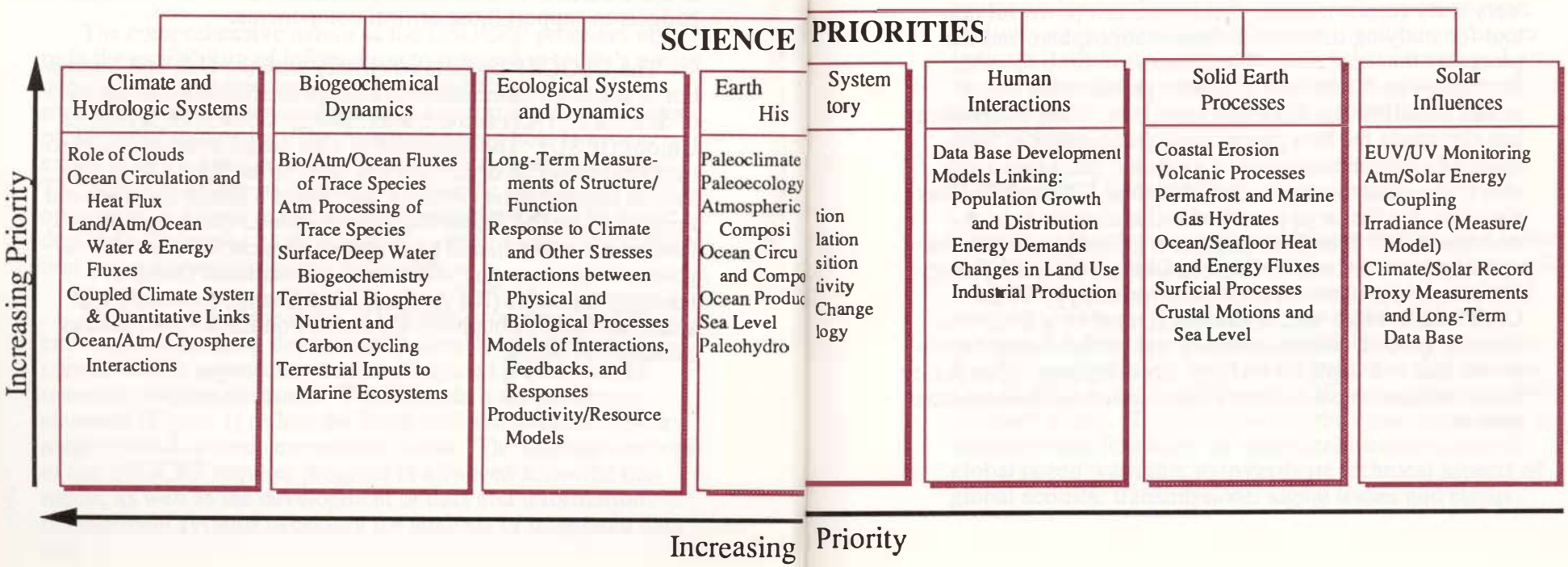
Figure 1
U.S. Global Change Research Program Priority Framework

STRATEGIC PRIORITIES

- Support Broad U.S. and International Scientific Effort
- Identify Natural and Human -Induced Changes
- Focus on Interactions and Interdisciplinary Science
- Share Financial Burden, Use the Best Resources, and Encourage Full Participation

INTEGRATING PRIORITIES

- Documentation of Earth System Change
  - Observational Programs
  - Data Management Systems
- Focused Studies on Controlling Processes and Improved Understanding
- Integrated Conceptual and Predictive Models



Recent Research Progress Toward USGCRP Objectives

This section contains a preliminary compilation of significant scientific progress in a sample of global change research efforts supported under the USGCRP. The material is arranged into three categories corresponding to the USGCRP objectives, i.e., observations, process research, and modeling and prediction. USGCRP contributions to policy issues are also briefly described.

1. OBSERVATIONS

Space Observing System Deployment:

The Upper Atmosphere Research Satellite (UARS) was successfully launched aboard the space shuttle Discovery on September 12, 1991. It was the first launch in Mission to Planet Earth's Phase 1. The satellite includes ten scientific instruments that have been designed to operate cooperatively for an integrated study of the energy input, chemistry and dynamics of the stratosphere and mesosphere. The satellite is performing at or better than specifications. Very early results indicate that UARS is a powerful new tool for studying ozone in the upper atmosphere and the processes that control it. The microwave limb sounder instrument on UARS has produced global maps which record details of the Antarctic ozone hole. The instrument has also made the first global-scale measurements from space of chlorine monoxide, a molecule that plays a key role in the catalytic destruction of ozone. The satellite has also detected the large plume of sulfur dioxide from the eruption of Mt. Pinatubo, mapped it globally, and simultaneously measured ozone concentrations within the plume. An intensive program is underway for analysis of the UARS data, which will be complemented by a large program of ground, balloon, aircraft, and rocket-based experiments that will exploit overflight opportunities. (See policy issues section below for more information on ozone related matters).

In August 1991, a second Total Ozone Mapping Spectrometer (TOMS) instrument was launched, this time aboard a Soviet Meteor spacecraft. This instrument will complement and provide redundancy for the current TOMS total ozone measurements which have been made since the launch of the Nimbus 7 satellite in 1978. The Shuttle Solar Backscattered Ultraviolet (SSBUV) Instrument, which makes space-based measurements of the total ozone and its vertical distribution to help provide calibration for the SBUV-2 instrument on NOAA's operational satellites, was also flown in 1991.

Mt. Pinatubo Volcano Eruption:

The Pinatubo volcano in the Philippines began an eruptive episode in early April 1991 and in June began to emit sulfur dioxide into the stratosphere in amounts observed from volcanoes only every 50 to 100 years. Within two weeks of the eruption the volcanic cloud surrounded the Earth at the equator, and it has since spread to higher latitudes. The eruption reached an altitude of 30 km and is expected to be detectable for several years by the increased amounts of stratospheric sulfate aerosols. The magnitude of volcanic emissions is such that it could provide a sudden forcing pulse on observable climate parameters and thus provide a mechanism to test models of climatic change; preliminary models of the effects of Pinatubo volcanism indicate it could retard the trend in global warming. Large increases in stratospheric sulfate aerosols could also affect the amount of ozone and other trace constituents in the stratosphere.

Heard Island Experiment:

Climate-induced changes in ocean temperature (and hence in sound speed) can be monitored by measuring changes in the travel time of acoustic signals from remote powerful sources. To develop and implement a global acoustic network for detection of climatic variability in the ocean, a feasibility experiment was carried out under the sponsorship of NOAA, NSF, DOD and DOE, during January 1991, at Heard Island. The objectives of the experiment were to determine the feasibility of acoustical measurements of global ocean warming; to investigate technical aspects of global acoustic transmissions: signal losses and clarity,

source reliability, receiver requirements, and effects on marine mammals; and to initiate collaboration between the U.S. CEES (USGCRP) agencies and international partners for a potential long-term experiment.

Nine countries participated in this experiment. Acoustic signals were successfully received globally, and no significant effects on marine mammals were observed. Detailed analysis of the signals is underway to establish a baseline for ocean temperature, which will serve as a basis for comparison in this multi-year, ongoing experiment.

Paleoclimate:

A number of paleoclimate studies supported by the USGCRP have generated significant new data on past climatic variations. These include:

- **Greenland Ice Sheet Project II (GISP II):**

  A 1,510 m ice core extending back approximately 8,000 years has been recovered on the summit of the Greenland ice sheet. Annual resolution of a variety of parameters (visual stratigraphy, dust content, and electrical conductivity) will permit a very precise dating of the core. A temperature history of the past 1,000 years has been derived from the core, and the natural background variability of temperature has been estimated to be on the order of 2 degrees Celsius. Analysis of carbon dioxide in air bubbles in the ice core shows a constant level of atmospheric carbon dioxide of 280 ppmv (tolerance of 5 ppmv) between 1530 and 1810 A.D. Thereafter, the atmospheric concentration rises abruptly. The record correlates well with the more recent direct atmospheric observations from Mauna Loa.

  Work is in progress to extract information on a large number of parameters which will provide data on atmospheric composition and climate over the last 8,000 years. Drilling at GISP II is expected to sample the entire depth of the Greenland ice sheet and is planned to be completed in 1993. This core will provide a climatic baseline record for the Northern Hemisphere extending back about 150,000 years before present, through two glacial-interglacial cycles.

- **Pliocene Warm Climate Reconstruction:**

  Substantial progress has been made on reconstructing conditions during the Pliocene, which is the last time that the Earth's climate was significantly warmer than the present. Estimates of environmental conditions have been obtained from deep sea cores and lake deposits. The reconstruction shows that during Pliocene warm intervals, sea surface temperatures in some areas of the North Atlantic and Arctic were as much as 5 degrees Celsius warmer than at present and that precipitation in the Alaskan and Canadian Arctic and western U.S. was higher. The data are being used to refine and test the ability of the general circulation models to accurately simulate past warm climates.

- **Southern Hemisphere Tree Ring Record from Tasmania**:

  The Southern Hemisphere has relatively few high resolution climatic time series that extend back more than 100 years. A climatically sensitive huon pine tree ring record from western Tasmania has been obtained through the cooperative effort of U.S. and Australian scientists that provides a thousand-year record of climatic changes in the Southern Hemisphere. This record allows inferences about Austral summer temperature changes since 900 A.D.

  Since 1965, huon pine growth has been unusually rapid. This growth increase correlates well with recent anomalous warming in Tasmania based on instrumental records. Although this temperature increase exceeds any that are inferred to have occurred during the past 1089 years at this location, it has not yet clearly emerged from the background variability of climate in this part of the Southern Hemisphere. The record also indicates a major cold episode during the early 1900s as well as an event of lesser magnitude around 1190 A.D. Both the medieval warm epoch and the Little Ice Age events are reflected in the record. Thus, the Tasmania tree ring record provides a unique opportunity for understanding decadal- to century-scale climatic fluctuations in the Southern Hemisphere.

Global Land Data:

The Global Land Information System (GLIS), an on-line system to provide information on global land data to scientists, managers, policymakers, educators and others has been implemented as a prototype portion of the interagency Global Change Data Information System. Among the many data bases available through GLIS is the land characterization digital data base, which contains information on land cover/vegetation, climate terrain and ecological regions for the conterminous U.S. In addition, periodically updated vegetation greenness data from Advanced Very High Resolution Radiometer (AVHRR) satellite measurements are routinely available for the conterminous U.S. (being expanded for North America) and North Africa. Other data of global nature are also available.

2. PROCESS RESEARCH

TOGA:

The objective of the international Tropical Ocean-Global Atmosphere (TOGA) program of the WCRP is to examine whether the coupled ocean-atmosphere system can be modeled to predict climate and its variations on interannual time scales. A notable degree of success has already been achieved in experimental forecasts of major swings in the El Niño-Southern Oscillation (ENSO) cycle, a season or more in advance, using statistical prediction techniques and simplified dynamical models of the coupled atmosphere-ocean system. Basic research involving the use of these simple dynamical models has yielded new insights into the nature of the ENSO cycle and the physical basis for predicting it. The coupled atmosphere-ocean system has been shown to exhibit modes of variability fundamentally different from those that could exist within the ocean and atmosphere, if they were not capable of interacting with one another. These models and the theoretical insights derived from them are serving as the groundwork for a more systematic exploration of the predictability of ENSO. Indeed, a national program (TOGA Program on Prediction) has already been established to assist in developing the present experimental efforts into a full-scale operational system.

WOCE:

The U.S. component of the international World Ocean Circulation Experiment (WOCE) of the WCRP has been developed in recognition of the significant and essential role that oceans play in long-term climate change. At any location, several years of ocean measurements are usually required in order to draw meaningful scientific conclusions about the general ocean circulation. Thus, the early focus of U.S. WOCE has been on comprehensive and long-term scientific planning and the development of robust measurement systems.

U.S. WOCE has demonstrated the capability of planning and developing the sophisticated measuring systems for describing the global ocean circulation. The measurement program has now commenced. New data on the general circulation of the Pacific Ocean are now being processed. Measurement systems have been put in place to study aspects of the abyssal circulation of the South Pacific and South Atlantic Oceans.

IGAC:

The Global Tropospheric Chemistry Experiment (GTCE) has conducted two major aircraft-based experiments as major components of the International Global Atmospheric Chemistry (IGAC) program of the IGBP. The first of these, the Atmospheric Boundary Layer Experiment, done jointly with Canada, was a combined aircraft and ground-based study performed in 1990 that has produced a new, extensive data base on emission of methane from high latitude wetlands and on the effects of long range transport of pollutants on an otherwise pristine part of the global atmosphere. The Pacific Exploratory Mission experiment, carried out jointly with seven Asian countries in 1991, addressed the impact of the Asian air mass on the western Pacific. It is the first of a series of missions that will study the effects of steadily increasing encroachment of pollutants on the western and central Pacific, which could have significant effects on the oxidative capacity of the global atmosphere.

JGOFS - The Atlantic Bloom Experiment:

The objective of the international Joint Global Ocean Flux Study (JGOFS) is to determine on a global scale the processes controlling the fluxes of carbon and other biogenic elements in the ocean, quantify the related exchanges with the atmosphere and the sea floor, and develop the ability to predict the response of these oceanic processes to anthropogenic disturbances that may contribute to climate change. The annual phytoplankton bloom offers a unique opportunity to observe some of these processes in action. The one-celled plants that form the base of the marine food chain undergo a population explosion each spring as light levels increase and the surface waters grow warmer, taking up nutrients and drawing down the supply of carbon dioxide in the water. Their growth and decay contribute to the transfer of carbon between the atmosphere and oceans and from the surface to the depths.

A pilot project of the JGOFS program, an eight-month study of the development, spread and decline of phytoplankton bloom in the North Atlantic, was conducted in 1990 by scientists from the U.S., the U.K., the Netherlands, Germany and Canada. The bloom study has resulted in the best data set that now exists for studying the seasonal progression of changes in the carbon cycle, including the air/sea exchange of CO_2. The experience gained during the North Atlantic Bloom experiment will form the basis for future measurement and analytical strategies in other ocean basins. Salient results of the experiment and its modeling components will be published in a dedicated volume of the journal Deep Sea Research.

FIRE:

The First International Satellite Cloud Climatology Project (ISCCP) Regional Experiment (FIRE) is designed to investigate the relationships between cloud systems and climate. FIRE Phase I (1895-1990) has produced fundamental new information on the formation, maintenance, and dissipation processes of cirrus and marine stratocumulus clouds including important radiative properties such as cloud reflectivity, optical depth, particle size, and liquid water/ice phase and optical path.

FIRE-II (1991-1995) combines intensive field observations, extended time observations, and modeling studies to further improve understanding of cirrus and marine stratocumulus clouds, validate cloud parameters deduced by ISCCP, and develop realistic cloud-radiation parameterization schemes for general circulation models. Two Intensive Field Observations (IFO) efforts are included in the plans for FIRE-II. The first, the cirrus IFO, was conducted during the Fall of 1991 in southern Kansas. It combined coordinated satellite, aircraft, and surface-based observations with modeling activities to establish a comprehensive data set for studying cirrus cloud processes. It included approximately 125 researchers from 40 research institutions from the U.S., Japan, Canada, Germany, Russia, and Switzerland. The second IFO, on marine stratocumulus cloud systems (Atlantic Stratocumulus Transition Experiment; ASTEX), will be conducted in June 1992, in the North Atlantic Ocean.

Other Earth System Processes (Hypothesis Testing):

Several hypotheses have been advanced to explain important Earth system processes. These have stimulated substantial modeling as well as field research under the USGCRP. Some of them are highlighted below.

- **Global Ocean Circulation:**

  The process of exchange between the ocean's warm surface layers and the cold deep ocean a mile or more down has been pictured as a global conveyer belt, driven by cooling in the polar regions. The time scale for this vertical exchange and circulation is between a century and a millennium. The horizontal and vertical motions in the ocean act like a huge flywheel driving the world's climate at a relatively steady pace. It is hypothesized that irregularities in the operation of the flywheel contribute to substantial climate change, such as during the last ice age when the conveyer belt may have slowed down and even stopped in the Arctic. Observational and modeling programs under the USGCRP are aimed at investigating this hypothesis.

- **Role of Water Vapor in Ameliorating Greenhouse Warming:**

  Understanding the role of water vapor, clouds, aerosols and radiation in climate processes and feedback is a high research priority of the USGCRP. Over the past few years, several provocative new ideas have emerged about these processes and feedbacks that bring into question earlier understanding. Some of these have evolved into hypotheses to be tested under the USGCRP. For example, although it is generally believed that water vapor produces the largest single amplifying climate feedback mechanism, understanding the details and magnitude of the feedback is complicated by the fact that water vapor's role as a greenhouse gas depends not only on the amount of water in the atmosphere, but also on its vertical distribution. However, the vertical distribution of water vapor is poorly known, particularly at higher levels in the upper troposphere where water-cloud-radiation processes could act to reduce significantly, the large positive feedback predicted by models. Both observational and modeling projects are being carried out to test hypotheses related to this feedback process.

- **Western Pacific Region Thermostat:**

  Another hypothesis being debated by scientists concerns the role of tropical clouds as a negative feedback (thermostat) on the climate system, especially the state of the sea surface temperatures in the western Pacific warm pool. The hypothesis suggests that in this region of high sea surface temperatures, as a consequence of surface warming, deep convection develops that produces highly reflective cirrus clouds, thus limiting further sea surface warming. Indeed, the surface temperatures in this region have never been observed to exceed around 30 degrees Celsius. A series of observations is being planned that will enable this hypothesis to be tested.

- **Anthropogenic Sulfur Dioxide:**

  Recent work and model calculations suggest that the atmospheric aerosols that are formed as the result of

anthropogenic emissions of sulfur dioxide may significantly affect the radiation balance in industrial regions and throughout the Northern Hemisphere. It has been hypothesized that direct scattering of solar radiation by these anthropogenic aerosols exert a climate forcing that is comparable in magnitude to that of carbon dioxide but opposite in sign, and that this forcing is in part delaying the onset of greenhouse warming at least in the Northern Hemisphere. Observations and model calculations are now being carried out to better understand the role aerosols can play in the Earth's radiation budget and the subsequent impact upon the climate system.

3. INTEGRATED MODELING AND PREDICTION

Increased Computational Power:

Two climate general circulation models (GCMs; the National Center for Atmospheric Research community climate model and the Semtner-Chervin eddy-resolving global ocean general circulation model) have been transferred to Lawrence Livermore National Laboratory's massively-parallel computers of the type now becoming available for some of the most demanding computational problems. This is a significant milestone toward achieving the goal of a factor of 10,000 increase in computational speed of global climate models between the years 1990 and 2000. This progress is the result of synergism between the USGCRP and the new Federal High Performance Computing and Communications (HPCC) Program. The restructured model code achieves performance on the massively-parallel computer, CM-2, that is comparable to that on a four-processor CRAY-XMP. Nearly a doubling of the model's speed and higher spatial resolution capability have been achieved by reformulating a key model algorithm. This is an important step toward achieving GCMs with higher spatial resolution that can be used for regional predictions.

Intercomparison of Global Climate Models:

The USGCRP supports the international model intercomparison project to diagnose the differences and similarities among atmospheric GCMs. The focus is on

quantifying important feedback processes, effects of varying model resolution on various predicted fields, and intercomparisons of different GCM simulations based on standardized data sets.

Among the main feedback processes investigated thus far are cloud-radiative and snow cover feedbacks. As climate changes, clouds may well change, enhancing or modifying the greenhouse gas-induced climate change through a process called the cloud-radiative feedback. While this feedback is of fundamental importance in predicting future climates, it is poorly understood. In a study of 19 GCMs, the cloud feedback differed by a factor of three. The root cause appears to be the differences in how clouds are modeled. Global warming due to increasing greenhouse gases may also reduce snow cover, thereby causing a positive feedback effect on global temperatures due to a resulting darker planet that absorbs more solar radiation. Intercomparison of 19 GCMs shows that such feedback effect predicted by GCMs ranges from weakly negative (cooling effect) to strongly positive (warming effect), indicating that the hypothesized feedback effect of snow cover change is overly simplistic and cannot be ascribed solely to an albedo change induced by snow retreat. Clouds are a significant cause of the interactive effects, i.e., the change in snow cover results in multiple feedbacks including changes in clouds.

Effects of GCM Resolution:

In order to investigate the effects of varying resolution in GCMs, the European Center for Medium Range Weather Forecasting (ECMWF) model has been run at the Lawrence Livermore National Laboratory at four different grid resolutions of 5, 3, 2 and 1 degree. Results indicate that below a 3 degree resolution, large-scale mean fields appear to be resolution independent. However, the variability of some fields may be resolution dependent, e.g., high resolution may be required to properly simulate the regional seasonal cycle. Moreover, the next generation of Earth system models will include coupled, interactive terrestrial components for which optimal resolution questions will have to be revisited.

Global Modeling of Methane Sources, Sinks, and Distribution:

A three-dimensional chemistry transport model has been used together with an extensive set of measurements of surface level methane concentrations in order to help constrain estimates of the methane budget, especially the distribution of sources (fossil fuel, domestic animals, wetlands, tundra, landfill, tropical swamps, rice fields, biomass burning, termites). Candidate scenarios were constructed using mass balance and isotopic information. By considering the calculated methane distributions, especially their latitudinal and seasonal dependence, a preferred budget was obtained. Accurate estimation of methane sources within certain groups (e.g., landfills, tropical swamps, rice fields, biomass burning, termites) cannot be uniquely determined at this time, however. Improvements in knowledge of the variability of methane and its climatology could lead to improved estimates of the methane budget.

Modeling Hydrologic Processes:

An improved representation of terrestrial hydrologic processes in the Geophysical Fluid Dynamics Laboratory (GFDL) GCM has demonstrated that GCMs greatly overestimate the value of potential evaporation and that modeled soil moisture is seriously underestimated in seasons of water shortage. The cause of these errors has been identified, explained and corrected in GFDL's GCM.

4. USGCRP CONTRIBUTIONS TO POLICY ISSUES

Stratospheric Ozone Depletion:

The CEES/USGCRP agencies play a key role in the stratospheric ozone depletion issue, including sponsoring and participating in international field campaigns as well as conducting analyses of ozone and atmospheric chemistry data from various sensors. Agency scientists and managers also participate in the International Ozone Assessments and the Montreal Protocol follow-ups.

Recent Major Findings:

- 1987: Ground, aircraft, and satellite data were used to establish a cause-and-effect relationship between anthropogenic chlorine and the observed springtime loss of ozone over Antarctica.

- 1988: Re-analysis of ground-based total column ozone data showed a statistically significant depletion in winter between 30 and 60 degrees in the Northern Hemisphere for the period 1969-1982.

- 1989: Aircraft data demonstrated that elevated levels of chlorine in the Arctic stratosphere in winter had significant potential to destroy ozone.

- 1991: Reanalysis of satellite total column ozone data (Nimbus 7 TOMS) showed a statistically significant ozone depletion in both the Northern and Southern Hemispheres poleward of 30 degrees, both in winter and spring over the period 1979-1990. Further analysis of TOMS and ground-based Dobson data showed ozone loss in both hemispheres at mid-latitudes in the summer as well.

- 1987-1991: TOMS data showed that there has been a deep Antarctic ozone hole four out of the last five years, and that the total ozone amounts observed in 1991 were the lowest ever. The severity of the ozone hole observed through much of the 1980s did not occur during the past three years.

- 1991: Initial UARS microwave data confirmed the presence of the Antarctic ozone hole and showed for the first time the distribution of ozone-destroying chlorine compounds with latitude, longitude and altitude.

Policy Implications of the Ozone Findings:

- 1989: The first three of the above findings were highlighted in the 1989 International Ozone Scientific Assessment which formed the scientific basis for the 1989 London revisions to the 1987 Montreal Protocol. Chlorofluorocarbon (CFC) and halogen

regulations were strengthened, and two additional chemicals, i.e., CH_3CCl_3 and CCl_4, were regulated.

- 1991-1992: The next three findings are highlighted in the 1991 International Scientific Assessment of Stratospheric Ozone which will form the scientific basis for the 1992 re-assessment of the London revisions to the 1987 Montreal Protocol. The adequacy of the current CFC and halogen regulations, as well as the potential need to regulate HCFCs will be examined in the context of minimizing further depletion of ozone over populated areas. In addition, the increased need for research on human health and ecological effects of UV radiation and CFC replacement chemicals is obvious.

Participation in International Policy Formation:

The USGCRP representatives actively participate in key roles on the U.S. delegation to meetings of the International Negotiating Committee (INC) for the Framework Convention on Climate Change and preparatory committee meetings for the U.N. Conference on Environment and Development (UNCED). The representatives have provided input on international scientific cooperation and multilateral observation systems for use by the U.S. delegations to these meetings. A Framework Convention on Climate is expected to be signed at the UNCED in June 1992 in Brazil.

International Scientific Infrastructure - Regional Institutes of Global Change:

The proposal for regional research institutes for global change research was mentioned by the President during the 1990 White House Conference on Science and Economics Research Related to Global Change. Three such institutes capable of linking the interests and capabilities of the developed and developing world are envisioned: one in the Western Hemisphere, one in Europe/Africa, and one in the Far East/Southwest Pacific. Planning for the Western Hemisphere Institute, now known as the Inter-American Institute for Global Change Research, has formally commenced. A regional planning workshop held in Puerto Rico in the Summer of 1991 resulted in a broad conceptual framework for the Institute and outlined a process for

further development of this framework leading to the establishment of the Institute in mid-1992. As currently conceived, the Institute is highly compatible with the Global Change System for Analysis, Research and Training (START) Initiative for regional research centers. Both initiatives focus on broadening global change research in the developing world, providing support for a truly multidisciplinary effort, and encouraging the development of a sound scientific underpinning to support national, regional, and international policy issues associated with global environmental changes.

USGCRP Data Policy Statement:

A national policy for global change data has been established through the cooperative efforts of the CEES and the efforts of the ad-hoc Interagency Working Group on Data Management for Global Change (IWGDMGC). The U.S. government has adopted policies for the management and exchange of climate and other global change data and related information, which will make such information readily available to scientists and other researchers worldwide. Seven principles, drafted over the last year by the IWGDMGC and the USGCRP Task Group on Observations and Data Management were recently approved by Dr. D. Allan Bromley, science advisor to President Bush and the Director of the Office of Science and Technology Policy. These principles, embodied in the policy, have been included in the plans of several U.S. agencies and the International Geosphere-Biosphere Programme (IGBP). The Second World Climate Conference incorporated a condensed version of the principles into its Scientific and Technical Statement in November 1991 (see Areas Needing Special Emphasis-Data and Information Management section for list of principles).

International Data Policy:

Agencies operating or planning space-borne Earth observations missions coordinate their plans through the informal international Committee on Earth Observations Satellites (CEOS). CEOS now includes representatives of major international science organizations as Affiliate Members to

enhance communication and responsiveness between satellite operators and international scientific user groups. CEOS addresses data management and calibration/validation through active technical working groups on these subjects.

CEOS recently adopted a resolution on data exchange principles at its December 1991 plenary meeting. These principles were proposed by the U.S., based on the USGCRP data exchange principles. CEOS recognized that "maximizing the use of satellite data is a fundamental objective" and requires an exchange/sharing mechanism among CEOS members. The CEOS principles call for preservation of all relevant data; easily accessible archives with appropriate supporting information; use of international standards for media, processing, and communication of data sets; elimination of any period of exclusive data use beyond an initial checkout and calibration period not to exceed three months; and harmony among criteria and priorities for data acquisition, archiving, and purging.

The FY 1993 Program

The President's FY 1993 budget continues the program outlined in the FY 1992 budget request by focusing on high priority and immediate scientific uncertainties associated with understanding changes in the Earth's climate system. The FY 1993 USGCRP request is designed to respond primarily to the following highest priority, near-term scientific uncertainties and information needs identified by the 1990 Scientific (Working Group 1) and Impacts (Working Group 2) Assessments of the U.N.-sponsored Intergovernmental Panel on Climate Change (IPCC):

- sources and sinks of **greenhouse gases**, and the processes that control them, which affect predictions of future concentrations;
- **clouds and radiative balance**, which strongly influence the magnitude of climate change at global and regional scales;
- **oceans**, which influence the timing and patterns of climate change;
- **land-surface hydrology**, which affects regional climate change and water quality;
- **polar ice sheets**, which affect predictions of global sea level changes; and
- **ecological dynamics**, which are affected by and respond to climate change.

In addition, recognizing that global change issues are set in a societal context with economic implications, the FY 1993 budget continues a program of basic and policy-oriented economics research related to global environmental change. The economics research agenda of the USGCRP is derived from the deliberations of the IPCC, the White House Conference on Science and Economics Research Related to Global Change held in April 1990, and the recognition within the economics community that substantial benefits to policymaking can be derived from such research.

Combining the IPCC areas of high priority research with the economics research agenda leads to an FY 1993 program designed to provide national and international policymakers with timely and accurate predictions and assessments of climate change, including its economic and human dimensions.

The long-term strategy of the USGCRP includes a comprehensive program of research that seeks to ensure:

- the development and maintenance of a **global-scale observing system** with local- and regional-scale resolution;

- the conduct of **focused research studies** to understand the physical, geological, chemical, biological, and social processes that influence the Earth system; and

- the implementation of an **integrated modeling, prediction and assessment** program.

In this regard, highlights of the FY 1993 budget request include the following:

Global Climate Observing System

The FY 1993 Program provides support for the first phases of a comprehensive global climate observing system (GCOS) as recommended by the IPCC 1990 Assessment, the Paris Summit of the G-7, and the Second World Climate Conference. This first phase includes (1) funding for a restructured Earth Observing System (EOS) taking into account related foreign satellite programs; (2) support for the Earth Probes program; (3) initiation of a DOE-sponsored program of small satellite-based measurements to support the Atmospheric Radiation Measurement (ARM) program (e.g., Earth radiation, water vapor, etc.); (4) development of climate measurement products from operational weather satellites and ground-based (primarily ocean) operational observing systems; and (5) the observational components of global-scale, international research programs like Tropical Ocean-Global Atmosphere (TOGA), World Ocean Circulation Experiment (WOCE), International Global Atmospheric Chemistry Project (IGAC), Joint Global Ocean Flux Study (JGOFS), Global Energy and Water Cycles Experiment (GEWEX) and Past Global Changes (PAGES). The planned support for the array of TOGA Atmosphere-Ocean (TAO) moored buoys, for instance, will provide the

first, basin-scale ocean-atmosphere observing system ever attempted. The USGCRP support for GCOS is being coordinated with the evolving Global Ocean Observing System (GOOS) which, inter alia, is integrating a number of existing ocean data collection and observing arrangements, and which is being developed in coordination with atmospheric observation arrangements.

Focused Process Studies

For FY 1993, many of the proposed augmentations to the USGCRP explicitly support international research activities and regional-scale U.S. research activities that will address the issues identified by the IPCC, and give high priority support for the following World Climate Research Programme (WCRP) and International Geosphere-Biosphere Programme (IGBP) efforts: TOGA, WOCE, IGAC, JGOFS, GEWEX, PAGES, Biospheric Aspects of the Hydrologic Cycle (BAHC), and Global Change and Terrestrial Ecosystems (GCTE). These activities direct resources to that portion of Earth system science where scientific advancement can enhance predictive understanding in the high priority research areas identified by the IPCC. This approach also fosters the international cooperation essential to rapid achievement of scientific understanding. However, pursuing a program focused on these IPCC recommended science and impact issues in the near-term will require continued interaction with the national and international scientific communities in discussions of scientific priorities.

The FY 1993 budget request enables CEES agencies to provide U.S. support for TOGA and IGAC programs and provide significant contributions for JGOFS. The CEES agencies place high priority on support for TOGA and IGAC since they represent two of the more mature international research programs and are both already producing results. The JGOFS Program is central to the quantification of fluxes between natural carbon sources and sinks and is, therefore, given a high priority by the CEES. The President's budget also permits formal U.S. participation in WOCE to understand the role of the ocean in climate change on decadal and longer time scales. The FY 1993 request will also enable development of the GEWEX Continental Scale International Program (GCIP) in the Mississippi River Basin, a particularly high priority effort to improve our understanding of the regional impacts of climate change.

CEES agencies will continue their support for research on specific components of terrestrial ecosystems and natural resources on a local scale with limited ability to extend the results to regional-scale integrated systems. In the marine environment, current embryonic efforts to understand the response of specific ocean and coastal environments and living resources to climatic change will continue.

The FY 1993 budget provides increased funding for research on economic, social, and health issues related to climate change. The increase will allow for expanded research on factors influencing human population dynamics and on the effects of changing populations on resources and environmentally sensitive zones. In addition, there will be a small increase in the number of research grants studying the effects of UV radiation and CFC replacement chemicals on human health.

Modeling, Prediction and Science Assessment

The FY 1993 budget enables the CEES agencies to undertake the integrated climate modeling, prediction and assessment effort so vital to providing consensus information to national and international decision makers. The CEES agencies have requested sufficient resources for a program to develop the first phases of a coordinated system of climate modeling and analytical centers around the country and they can continue efforts to establish an international prediction center to provide forecasts of interannual climate variability based on the El Niño-Southern Oscillation. The principal focus for USGCRP modeling efforts during FY 1993 will be continued development of enhanced coupled global ocean-atmosphere modeling capabilities. By the mid-1990s, the USGCRP will augment that effort to include the development of first-order global models with limited coupling of land-surface processes to those of the ocean and atmosphere. Climate forecasts on both seasonal and interannual timescales are likely by the second half of this decade.

The USGCRP representatives are actively participating in the ongoing review of the 1992 update to the 1990 Scientific Assessment of Climate Change prepared under the auspices of the IPCC.

Research Program and Budget

This section highlights the FY 1993 USGCRP budget by integrating theme, by science element, by scientific objective, by agency and by federal budget function. The President's FY 1993 budget proposes a funding level of $1,372.4 million, a $262.6 million (24 percent) increase over the FY 1992 enacted level.

Budget by Integrating Themes

In FY 1992, the CEES adopted four high priority integrating themes that enable the participating agencies to focus the collective effort of government and academic scientists, in collaboration with scientists from other countries, on multidisciplinary investigations directed toward some of the most critical global change research issues. The four integrating themes are: (1) Climate Modeling and Prediction; (2) Global Water and Energy Cycles; (3) Global Carbon Cycle; and (4) Ecological Systems and Population Dynamics. A detailed description of the integrating themes and the FY 1992 plans for the CEES agencies is contained in the FY 1992 edition of this document (*Our Changing Planet: The FY 1992 U.S. Global Change Research Program*) which accompanied the President's FY 1992 budget request to the Congress.

This section summarizes the FY 1993 activities by the four integrating themes. Table 1 and Figure 2 show the USGCRP FY 1993 budget by integrating theme. A few critical USGCRP activities do not fit within one or more of these integrating themes, e.g., stratospheric ozone, solid Earth processes, human interactions, solar influences, and economics research. These activities are included in the "other research activities" category. The following subsections summarize plans, many of which involve international research partners, for the FY 1993 research effort under each of the integrating themes.

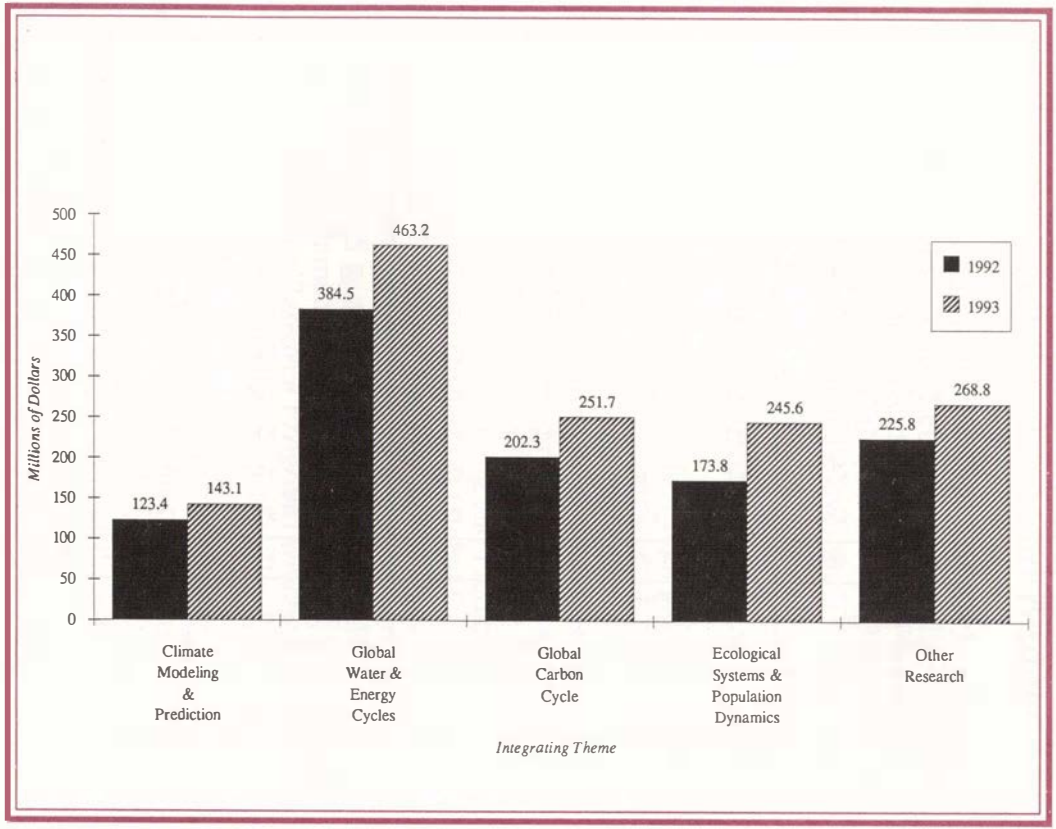
(1) ***Climate Modeling and Prediction:*** To develop an improved predictive capability of the Earth as a coupled system with enhanced regional resolution, with initial priority given to the climate system. The FY 1993 request for this integrating theme is $143.1 million, a $19.7 million or 16% increase over the FY 1992 enacted level.

Table 1
FY 1992–1993 U.S. Global Change Research Program Focused Budget by Integrating Theme
(Dollars in Millions)

	Total Budget		Climate Modeling and Prediction		Global Water and Energy Cycles		Global Carbon Cycle		Ecological Systems & Population Dynamics		Other Research Activities	
	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993
Agency Totals	1,109.8	1,372.4	123.4	143.1	384.5	463.2	202.3	251.7	173.8	245.6	225.8	268.8
DOC/NOAA	47.0	78.2	9.3	18.0	24.4	39.3	10.5	14.5	0.9	2.4	1.9	4.0
DOD	6.3	6.6	0.0	0.0	4.8	5.0	0.3	0.4	1.0	1.0	0.2	0.2
DOE	77.0	113.0	20.9	21.7	38.4	47.5	12.7	14.4	3.8	4.0	1.2	25.4
DOI	39.4	35.8	0.2	0.3	17.0	13.4	7.3	6.5	13.6	13.8	1.3	1.8
EPA	24.0	26.0	1.2	1.6	0.0	0.0	15.1	15.8	6.8	7.7	0.9	0.9
HHS	1.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.2	0.0	0.0
NASA	755.9	890.8	83.0	86.9	254.1	295.3	120.4	150.3	101.2	152.4	197.2	205.9
NSF	108.5	162.5	8.0	13.8	37.7	54.6	26.3	37.4	17.5	28.7	19.0	28.0
Smithsonian	6.3	10.6	0.0	0.0	0.3	0.4	1.0	2.0	4.5	7.4	0.5	0.8
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	44.3	47.6	0.8	0.8	7.7	7.6	8.7	10.4	23.5	27.0	3.6	1.8

Figure 2

U.S. Global Change Research Program by Integrating Theme



The FY 1993 research under this theme is structured to develop a predictive capability for the Earth as a coupled system. The USGCRP activities of observations, data management, and understanding all contribute to model development, documentation, testing, application and verification. While initial emphasis is on climate modeling, the 1993 request of $147.0 million is to support modeling activities across all of the science elements. Highest priority is given to Climate and Hydrologic Systems, Biogeochemical Dynamics, and Ecological Systems and Dynamics.

A strong and focused multi-agency program includes the development, application, and validation of global predictive models of climate change. It involves complementary and coordinated research which will be carried out by DOE, NASA, NOAA, NSF, EPA, DOI, and USDA, with emphasis on the following:

- data assimilation and production of GCM-assimilated climate data sets for model development and evaluation and for assessing climate trends and fluctuations;

- improved process representation (parameterizations) and regional resolution, and the separation of natural climate changes from those associated with human activities;

- development of advanced computational methodologies and capabilities for integrated climate models of the future; and

- integration of subsystem models (atmospheric, oceanic, and land-surface) to build the coupled climate system models.

(2) ***Global Water and Energy Cycles:*** To improve the understanding of the water (precipitation, evaporation/evapotranspiration, soil moisture, ice quantity, type and movement) and energy cycles (warming/cooling, radiative balance, solar variability, latent heat) by focusing on the following:

- the role of clouds: primarily the role of water vapor and cloud formation, cloud dissipation and radiative properties;

- the role of the oceans: the exchange of energy and mass between the ocean, sea ice, and the atmosphere; between the upper layers of the ocean and the deep ocean; and transport within the ocean;

- the role of terrestrial ecosystems: the exchange of energy and water and other substances between the atmosphere and the surface of managed and natural terrestrial ecosystems and soils; and

- the change in sea level: an integrated Earth system response to changing climate conditions, by examining the role of polar ice sheets and thermal expansion of the oceans and melting of land glaciers.

The FY 1993 request for this integrating theme is $463.2 million, a $78.7 million or 20% increase over the FY 1992 enacted level.

FY 1993 Research under this integrating theme will include:

Atmosphere: Continuing activities include NASA, NOAA, and NSF support for the International Satellite Cloud Climatology Project (ISCCP); the Phase II First ISCCP Regional Experiment (FIRE); the Stratocumulus Transition Experiment (ASTEX) (NASA, DOD, NOAA, NSF, and DOE); the NASA Earth Radiation Budget Experiment (ERBE); the NOAA Global Precipitation Climatology Project (GPCP); estimates of clouds and radiation from geostationary and polar-orbiting satellites (NOAA); the Global Energy and Water Cycle Experiment (GEWEX: NOAA, NASA, NSF, DOE and DOI); the Atmospheric Radiation Measurement (ARM) program focusing on extensive ground-based measurements of clouds and radiation and the Quantitative Links program to examine the relationships between atmospheric composition and global climate change (DOE); and NSF's Role of Clouds Energy and Water program, targeted specifically towards quantifying the radiative effects of clouds on a global scale. The Greenland Ice Sheet Program (GISP) will produce new data on paleoclimate; NASA's Tropical Rainfall Measuring Mission (TRMM) will quantify precipitation in lower latitudes.

Ocean: The continuing research focus is on general circulation of the ocean and basin-scale studies of particular modes of ocean-atmosphere interaction. NSF, NOAA, NASA, DOD and DOE will continue support of WOCE. *In situ* ocean observation systems (NOAA, NSF, DOI and DOD) will contribute to studies of ocean circulation and the coupling of the ocean and the atmosphere (TOGA-COARE), while the new generation of space-based measurements of ocean altimetry, temperature, and wind stress (TOPEX/Poseidon, NASA Scatterometer/ADEOS, NASA EOS) will provide the global context to these observations. Prior to EOS, a critical global data set for hydrologic cycle issues will be provided by the NASA Scatterometer, which will fly on the Japanese Advanced Earth Observing Satellite (ADEOS). Several agencies (NSF, NOAA, DOI, SI, and DOD) will conduct paleooceanographic studies to provide improved documentation and understanding of past changes in deepwater formation and circulation.

Land Surface: Agencies involved in regional-scale hydrologic modeling include DOI (Interaction of Climate and Hydrologic Systems, Regional Studies, Sensitivity of Hydrologic Systems, Sensitivity of Water Resources), DOD (Coupled Hydrologic/Thermal Basin Modeling), USDA (Scale Effects of Hydrologic Processes), and NASA (International Satellite Land Surface Climatology Project, BOREAS). Basic representation of landscape attributes will be provided by the Land Characterization program of DOI. Support for basic research on processes such as groundwater and reservoir recharge will be provided by NSF's Continental Hydrologic Processes program. Integration for many of these projects will be provided by the GEWEX/GCIP program, which will initiate a continental-scale study in North America. Paleoecological studies in NSF, DOI, USDA, and SI will provide information on past changes in global water and energy balances.

Sea Level: There will be enhancements to the Global Sea Level Monitoring Network (NOAA); ice sheet observations (DOI and NASA); monitoring of glacier mass balance (DOI); general circulation modeling related to sea level change (NOAA, DOE, NASA, and NSF); and crustal motions and sea level (NASA, NOAA, and NSF). Effort will also be devoted to understanding past variations in sea level, including continued support for the second Greenland

Ice Sheet Project (GISP II) which will recover a 150,000 year record from ice cores from Greenland (NSF); high resolution paleoclimatic records (DOI, NSF, and NOAA) containing several centuries of records preserved in corals, ice-cores, and varved sediments; the Abrupt Climate Change program (NSF); and the reconstruction of sea level history and its relationship to climate change (DOI).

Modeling: As described in the Climate Modeling and Prediction integrating theme, complementary interagency (DOE, NASA, NOAA, NSF, and DOI) research will emphasize the integration of subsystem models (atmospheric, oceanic and land surface) to build the coupled climate models necessary for improved predictions of climate change.

(3) ***Global Carbon Cycle:*** To improve the understanding of the carbon cycle by quantifying the natural and anthropogenic terrestrial and oceanic sources and sinks of key carbon compounds (e.g., carbon dioxide, methane and ozone precursors such as carbon monoxide and the non-methane hydrocarbons), including their chemical reactions in the atmosphere and oceans; by studying the chemical, biological and physical processes that control their fluxes and how these fluxes may be influenced by climate change; and by studying how changes in greenhouse gas abundances affect the magnitude and rate of change.

The FY 1993 Request for this integrating theme is $251.7 million, a $49.4 million or 24% increase over the FY 1992 enacted level.

FY 1993 Research under this integrating theme will include:

Atmospheric Carbon: DOE and NOAA will continue to monitor the temporal and spatial distribution of atmospheric carbon dioxide, including its isotopic composition. NOAA will expand its monitoring, including additional sites and vertical profiles at selected sites. NSF and DOI will utilize glacier ice core and tree ring data to document past changes in atmospheric carbon dioxide. DOI will monitor carbon dioxide emissions from volcanoes. NASA and NOAA will utilize intercalibrated *in situ* measurements from networks of ground-based stations and regular aircraft

flights to establish the global abundance of methane and its change with time. Measurements of methane will be complemented by a limited number of isotopic composition studies of contemporary atmospheric methane, and methane trapped in glacier ice cores (NASA and NSF). The NOAA baseline observatories will begin regular measurements of carbon monoxide. Instruments are being developed under NASA's EOS program, which will begin mapping global vertical distributions in the troposphere of methane and carbon monoxide and estimate column amounts of a large number of other constituents late in the decade.

NASA, NOAA, NSF, DOE, and EPA will perform laboratory kinetics studies, conduct field measurements, and carry out diagnostic modeling to improve our understanding of the atmospheric cycling, distribution and transformations of ozone, hydroxyl radical, nitrogen oxides, carbon monoxide, and non-methane hydrocarbons that control the distribution and lifetime of methane. NOAA will emphasize understanding the isotopically-dependent processes that remove methane. Field measurements will be done as part of process-oriented studies in remote regions, such as the NASA-organized IGAC regional projects in the tropics (Brazil), northern wetlands (Canada), and the eastern Pacific. The focus has been and will be airborne campaigns aimed at the processes occurring in the tropical Atlantic and western Pacific, and boundary-layer/free-troposphere studies in the continental U.S. and Atlantic. The NSF, NOAA, and DOE studies will continue to use Mauna Loa as a remote site.

Oceanic Carbon: NSF, NOAA, DOE, and NASA are all active participants in the international Joint Global Ocean Flux Study (JGOFS), a core project of the IGBP, the goals of which include understanding the transport and transformations of carbon and other biogenically important elements within the ocean and a quantification of the atmosphere - ocean exchange of carbon dioxide, hence understanding the role of the oceans in controlling the build-up of carbon dioxide in the atmosphere. NSF, NOAA and DOE will expand measurements of ocean carbon chemistry, including *in situ* studies of the chemical, geological, biological and physical processes responsible for controlling the distribution and exchange of oceanic carbon and

other biogenically important elements between the ocean margins, open surface waters, deep oceans, and sediments. NOAA and DOE will utilize networks of automated buoys and ship transects to determine the spatial and temporal concentrations of carbon dioxide in surface waters and to quantify the air-sea fluxes of carbon dioxide. DOD will further refine instrumentation to continuously estimate biological productivity responsible for the fluctuations in oceanic carbon in high latitude surface waters. The data from JGOFS will be complemented by an improved understanding of air-sea exchange processes and ocean circulation processes, particularly the exchange of water between the surface layer and the deep ocean, from the WCRP, WOCE, and TOGA programs, which are actively supported by NSF, NOAA, DOE, and NASA.

A number of *in situ* studies will be complemented in the future by remote sensing measurements from NASA's ocean color mission; NASA's Scatterometer (NSCAT) on ADEOS; and EOS missions of ocean biological productivity, sea surface temperatures, and surface winds, which will help characterize carbon dioxide fluxes across the air-sea interface. Launch of these smaller missions will occur between 1993 and 1995, and the EOS missions are expected at the end of the decade.

Terrestrial Carbon: DOI, NSF, EPA, DOE, NASA, and USDA will study, using *in situ* and remote sensing techniques, the biogeochemical processes responsible for the sequestering and release of carbon dioxide and methane and the storage (soils and vegetation) and cycling of carbon and other key nutrients (e.g., nitrogen and phosphorus) within a large number of diverse natural (boreal and tropical forests, tundra, grasslands, and wetlands) and intensively managed (e.g., commercial forests, rangelands, and agricultural systems) terrestrial ecosystems.

NASA, NOAA, NSF, EPA, DOI, DOE, and USDA will each study the fluxes, as well as the biogeochemical processes controlling them, of methane from one or more key sources, such as natural terrestrial ecosystems (e.g., tropical and boreal forests, grasslands, and high latitude peatlands), agricultural systems (particularly rice paddies), oceans and freshwater systems, managed forests, domesticated ruminants, termites, biomass burning, landfills, venting of

natural gas, methane hydrates in terrestrial and marine sediments, and coal mining. The emphasis will be on mechanistic studies, so that process and global-scale models can be developed and used to assess current methane sources and predict future changes in these sources.

USDA will measure gaseous emissions from forests under different climatic and disturbance (e.g., deforestation) regimes. NOAA will carry out tower measurements at selected sites, combined with modeling analyses, to estimate regional carbon dioxide sinks. EPA will focus on local ecological and biological processes that control fluxes of carbon and nutrients, primarily in high latitude ecosystems and secondarily in temperate and tropical ecosystems, e.g., biomass burning.

DOE conducts basic research on direct effects of carbon dioxide on vegetation, including control by carbon dioxide of fundamental biological processes such as photosynthesis, transpiration, and overall growth responses of plants.

Several existing research and monitoring programs will contribute to monitoring storage and movement of carbon and nutrients within ecosystems. DOI will provide relevant data on tundra permafrost melting and on the release of methane and stored carbon, and will integrate relevant baseline data on natural ecosystems. The USDA will provide biological data relevant to carbon and nutrient storage in terrestrial ecosystems in the U.S., as will continuing observations from NSF's Long-Term Ecological Research (LTER) and Land Margins Ecosystem Research (LMER) networks. USDA will test the hypothesis that the 25% increase in atmospheric carbon dioxide has increased the amount of carbon stored in the soils underlying croplands, pastures, and forests. EPA will assess the ability of tree-root and soil systems to sequester carbon; this ability may be an important physiological control of carbon storage. DOI, USDA, and EPA are developing methods of measuring the movement of carbon compounds within terrestrial systems and from terrestrial to coastal systems. An emphasis will be on the sensitivity to physical parameters, such as water content of soils, and the relation to ecosystem properties and responses.

NSF, NOAA, DOI, SI and USDA will conduct paleoecological studies utilizing geochemical, isotopic, and paleontologic data to understand past rates and magnitudes of uptake and release of carbon through terrestrial systems as monitored by changes in vegetation and environments, and organic content of sediments, including permafrost, and soil development.

DOI, EPA, NOAA, DOE, and NASA will utilize existing satellite imagery (e.g. Landsat and AVHRR) for land-cover classification and vegetation-index analysis, and to estimate changes in land use and the biological productivity of terrestrial ecosystems. Satellite data will be used in conjunction with ground-based and aircraft experiments to scale processes observed at the site level to the regional scale. NASA is developing a complement of surface imagers on EOS to expand this capability, and planned experiments in the International Satellite Land Surface Climatology Project (ISLSCP) will provide improved methodologies. The increased spectral and spatial specificity of NASA EOS instruments - High Resolution Imaging Spectrometer (HIRIS) and Moderate-Resolution Imaging Spectrometer (MODIS) - for ecosystem studies may provide the capability to monitor changes in nutrient storage from satellite data. ISLSCP is a contemporary program, while EOS measurements are planned to begin late in the decade.

Human Dimensions of the Carbon Cycle: DOE and EPA will be supporting extensive programs of research into human interactions in the carbon cycle. They will characterize anthropogenic emissions sources and project changes in the rates of emissions over time. DOE and EPA will also support research on the influence of anthropogenic carbon emissions on climate. DOE will examine industrial and technological consumption of fossil fuels and predict future consumption under different technologies.

The role of fire and terrestrial vegetation as sources of carbon production will be the focus of research in the USDA. Human interactions in tropical agroforestry and in arctic ecosystems will be examined by SI and by DOI. NSF will examine social and economic influences on and incentives in carbon production. DOI and NSF will support research on changes in land use.

Global Carbon Models: There are a number of agency activities that will eventually lead to improved global carbon-cycle models. DOE, DOI, EPA, NASA, NSF, and USDA will carry out a broad range of process-oriented and global-scale modeling studies to simulate global terrestrial carbon-cycling processes, including the coupling between the carbon cycle and water and energy fluxes from terrestrial and near-coastal ecosystems. These efforts include the use and the development of diagnostic and prognostic models of global carbon balances, which include the effects of deforestation, the uptake and release of carbon dioxide by terrestrial biota, and how these are influenced by changing climatic and other environmental conditions.

DOI, DOE, NOAA, NASA, and NSF will develop improved ocean carbon models, including satellite data assimilation, some of which will incorporate chemical and biological processes into three dimensional ocean general circulation models. NASA, NOAA, NSF and EPA will develop multi-dimensional tropospheric photochemical models to determine the atmospheric lifetimes of methane and carbon monoxide, and to evaluate how changes in trace gas emissions will affect the chemical composition of the troposphere, and hence atmospheric lifetimes. NSF and DOI will develop models to simulate observed variability in paleocarbon records.

(4) ***Ecological Systems and Population Dynamics:*** To improve the capacity to assess the effects of global change at regional scales. Specifically, to improve understanding of the responses of intensively managed and natural oceanic and terrestrial ecosystems to global change by focusing scientific research on the following:

- species composition, structure, and function of ecosystems;
- distribution and extent of ecosystems; and
- productivity of ecosystems.

The FY 1993 Request for this integrating theme is $245.6 million, an $80.8 million or 46% increase over the FY 1992 enacted level.

FY 1993 Research under this integrating theme will include the following:

Sampling, Monitoring, and Database Development: Using remotely sensed data from Landsat, AVHRR, Coastal Zone Color Scanner (CZCS), Scanning Multichannel Microwave Radiometer (SMMR), and Special Sensor Microwave/ Imager (SSM/I)), NASA and NOAA are providing synoptic observations of many of the world's terrestrial and marine ecosystems. DOI and other agencies are using these observations to document current ecosystem state, surface-cover type, and usage patterns. These observational programs are enhanced by EPA and NASA research that provides quantified methods to analyze these data for land use and cover on continental scales. EOS starting in 1998 will continue the satellite record, providing a 15-year continuous record of observations of change over time and intrinsic ecosystem variability.

Several agencies are making ground-based, direct long-term observations of ecological phenomena, documenting natural variation and changes in rate or amplitude of that variation. In a variety of remote areas that are substantially free of human influences, DOI is conducting longer-term, baseline observations. NSF's LTER Program supports long-term studies of natural populations over appropriate temporal and spatial scales to provide the basis for understanding changes in population abundance, distribution and occurrence of local and regional extinctions. NSF (Global Ocean Ecosystems Dynamics (GLOBEC and LMER) and NOAA (Marine Ecosystem Response Program) will provide an understanding of the natural variability of marine populations. Long-term data from DOE's National Environmental Research Parks provide a basis for assessing changes and separating them from changes resulting from human influences. The USDA is providing long-term monitoring of the productivity, health and diversity of agriculture, forest and range ecosystems, and DOI is conducting long-term monitoring of selected fish and wildlife species. DOI is comparing selected ecosystems at different elevations and latitudes at varying climatic extremes to provide an understanding of the ability of natural and managed systems to adjust to changes in their climatic constraints. The SI will focus primarily on tropical forest and marine ecosystems.

DOE, USDA, NSF, DOI and EPA will gather data related to population size, distribution, and land use. The same agencies will acquire information on economic activities, including the human factors in the use of natural resources and emission of gases and other substances by industries. NSF will support basic research projects that generate data on related topics. DOI will investigate the effect of global change on ecosystem use by native societies.

Dynamics of Growth and Decline: NSF, USDA, DOI, DOE, SI, and EPA are all conducting physiological studies of individual plant and animal responses to climatic variability. These studies, which use both laboratory and field-based experimentation and observations, evaluate the physiological sensitivity of species to climate change. NSF (GLOBEC) and NOAA are developing a mechanistic understanding of the processes determining the variability of marine animal populations in space and time, in particular the physiological and genetic responses of marine populations and species to change, and the interaction of population dynamics and the dynamics of ocean physics from micro- to basin-scale. Both climatic stresses and physiological stress from increased UV-B flux are being investigated by NSF, EPA, USDA, DOI, and NOAA. NSF, NOAA, DOI, USDA, and SI provide badly needed data on the natural histories and population dynamics of plant and animal species. Paleoecological studies by DOI and SI will provide critical long-term historical information.

On population and community scales, NSF (Ecological Rates of Change (EROC)) and NOAA will focus on the roles of ecological and biological interactions, such as competition, predation, parasitism, and pollination in determining the character of species' assemblages and rates of population changes under future conditions of global change. DOI will examine the spatial and temporal changes of species assemblages in ecotones, relict communities, and along altitudinal gradients. USDA will focus on determining changes in the occurrence and intensity of fires and disease outbreak. Additionally, NSF, NOAA, DOI and USDA programs will investigate how species interact competitively and in predator-prey relationships.

NSF will sponsor fundamental research projects that analyze factors that influence human population dynamics,

e.g., rapidly changing economic and environmental conditions that affect migration. Ongoing coastal-resource research and management activities in NOAA and NSF will improve the understanding of the effects of changing populations in coastal regions. USDA will conduct research on the ways in which population location decisions affect patterns of local and regional resource use and will identify the potential demographic effects of changing global environmental conditions. NSF will sponsor analyses of the ways in which rapidly expanding populations are altering environmentally sensitive zones in the U.S. and elsewhere. NIEHS will support research on the human health effects of UV radiation and CFC replacement chemicals.

Terrestrial disturbances (e.g., fire and windthrow) will be studied at a landscape scale. NSF will focus on the roles of ecological and biological interactions, such as competition, predation, and parasitism in determining the character of species' assemblages under future conditions of global change. USDA will concentrate on the influence of fire and pathogens. DOI will conduct studies on the linkages between terrestrial and aquatic community dynamics at this level, and on the impacts of global change on biodiversity.

Resource Accounting: NSF and other agencies will plan and conduct pilot analyses in order to move toward establishment of a set of Long-Term Regional Research Sites (LTRRs) at which both standardized and site-specific data on human activities and related natural environmental conditions will be gathered at several spatial scales. DOI will provide land-use, geologic and hydrologic data. NOAA will provide population data and, in coastal settings, hydrologic and land-use data, and USDA will provide data on soils and agricultural practices, as well as sponsoring work on the development of international measures of agricultural production practices, production levels, input levels and prices. USDA will provide data for forest resources from their experimental forests, Forest Inventory Assessments and the Forest Health Monitoring Program.

NSF will give special attention to comparative analyses of risk assessment and decision-making procedures in different types of institutions and the determination of means whereby intangible costs and benefits may be more effec-

tively integrated into decision-making procedures. DOI will study how institutions make trade-offs among social, economic, and environmental goals and how those trade-offs affect resource management strategies.

USDA and DOI will reconstruct data on historical land-use patterns, forest and vegetative cover, agricultural production levels and practices, and human settlement forms, in addition to monitoring. DOI, NSF, USDA and NOAA will all analyze the impacts of different management practices on water flow and quality. DOE will develop improved characterizations of the human factors in energy technology, energy resources, and the potential savings for technological developments and conservation by energy users.

Prediction of Threshold Responses: NSF, DOI, SI, and EPA will investigate the processes contributing to species diversity and the responses of species to habitat fragmentation and/or loss as a function of global change. GLOBEC will focus on coupled physical-biological models with three themes: conceptual studies of simplification and predictability, site specific models prior to field programs, and the influence of idealized flows on processes. USDA will enhance its fire and disturbance studies in order to better predict species responses under global change.

Modeling: On landscape-to-global scales, NSF, USDA, DOE, DOI, and NASA will develop nested, hierarchical models of ecological systems. Process models will be integrated into Geographic Information Systems (GIS) and then compared. As an additional method, NSF and EPA are constructing and testing rule-based and response-surface models, which derive possible system sensitivities and rates and types of population response to global change.

USDA will develop models to evaluate the relationships among global agricultural production, new agricultural technologies, international trade, sectoral competitiveness, and the changing global environment. EPA will continue to analyze emissions-forecasting models to provide better estimates of how various economic, technological, societal, and resource-use conditions influence future emissions. DOI will improve methods to assess the global change impacts on natural resources.

DOE will model interactions of the production and use of energy with other elements of the economy. EPA's contribution will be to investigate the human factors that influence the extent and magnitude of biomass burning and anthropogenic methane emissions.

The four integrating themes, and the agency projects which support them, do not, however, represent the USGCRP in its entirety. While these integrating themes provided a principal focus for major funding enhancements in FY 1993, the President's budget request also includes resources to enhance support of economics research related to global change and resources to maintain programmatic momentum in a number of other critical USGCRP supported research areas. These include continued support for investigations in the areas of stratospheric ozone, human interactions, solid Earth processes, and solar influences.

Budget for Economics Research Related to Global Change

The critical role of economics in global change questions was widely acknowledged by President Bush and world leaders at the April 1990 White House Conference on Science and Economics Research Related to Global Change. Ministers at the Second World Climate Conference, referring to the completed reports of the IPCC, reconfirmed the need for economics research to resolve critical uncertainties.

Economic relationships are fundamental to understanding the potential magnitude of global change as a problem for human society and for assessing and developing effective responses. Responses to the threats posed by global change are investments for ourselves and for future generations. The calls on society's investment resources are many, yet these resources are limited. The central focus of economics research is to make informed decisions that involve the allocation of scarce resources among competing demands.

Substantive research priorities for economics are

- Economic Forces and Global Environmental Change
- Impacts and the Adaptation of Economic Systems
- The Value of Information and Decision Making Under Uncertainty
- The Economics of Technology and Practice Linked to Global Environmental Change
- Policy and Policy Instrument Evaluation

For FY 1993, the USGCRP supports the Federal research program on the Economics of Global Change with a proposed budget of $12.7 million. This is an increase of $8.0 million, or nearly triple the funding level of $4.7 million appropriated for FY 1992. The program has made significant strides with the research investment in economics made to date but is in danger of failing to meet the immediate demands of the policy process. Analyses being directly used in policy discussions are not, in many cases, based on sound economic reasoning because research funding has lagged behind the need. Those working in the field have been spread very thin and have provided input to policy but this has meant that critical methodological improvements and modeling efforts in which they were involved have been delayed.

Recognizing these shortcomings, the Federal research program on the Economics of Global Change has identified three critical thrust areas for FY 1993 that cut across agencies and elements. While funding increases cover a wide range of important topics, the focus for the FY 1993 program is directed toward these thrust areas. They include the following:

1. Global economic models for analysis of global environ mental change.

NSF's review of proposals in this area found that there were serious methodological, substantive, and data problems that need to be addressed to improve the credibility and usefulness of economic models. While the development of improved models is a significant challenge, no one seriously questions the need to investigate the effects and

responses of global change within the context of global markets and trade. Nor is there any question that changes in the transition economies of Eastern Europe and the course of growth and development in developing countries will critically affect the magnitude of global change and the ability of the U.S. and other nations to manage its response to such changes.

NSF is currently supporting efforts by the Energy Modeling Forum to tie key policy analysis issues on global environmental change to the basic social science needed to improve existing economic models. Among the new projects funded by NSF are models of the economic effects of greenhouse gas restrictions on developing countries, models of trade and environment, and studies of short- and long-term determinants of growth. DOE is supporting significant new economic models of trace gas emissions. USDA is developing new models linking food needs and supplies to potential environmental change.

2. Uncertainty and the value of information.

Global change is highly uncertain. Uncertainty and risks, in themselves, are neither an excuse for inaction nor a justification for rash action that may be extremely costly to the economy. NOAA proposes a significant increase in funding to identify the physical variables needed for economic analysis of the effects of global change. This effort is at the heart of developing the interdisciplinary linkages that can reduce uncertainty. NOAA is well positioned to lead this effort because it is also a center for physical science research on global change. Characterizing uncertainty and identifying strategies and options that make sense given existing uncertainty is a significant theme across all efforts, including, for example, the area of global modeling and effects.

NSF is emphasizing the basic research needed to provide better tools for analyzing the types of risks associated with global change. NSF research projects include work on irreversibility of investment decisions and global warming; incorporation of uncertainty and irreversibility into spatial tropical forest models; and studies of risk perception, risk communication, and risk assessment.

3. The economic effects of global change.

Measuring the potential economic effects of global change has posed a significant challenge to research, yet advances in this area offer the highest payoff in better national and international decisions. Analyses to date have not been geographically comprehensive, nor has research yet progressed to the stage that there is a high degree of confidence that all of the important indirect links of climate and resources to the economic well-being have been identified, much less quantified.

A major NSF project is underway on the economic and social impacts of global change, with special attention given to the collection of a county-level data base on climatic conditions and economic activities in the United States. NSF workshops on industrial microdata and on international household data highlighted the importance of linking economic, global change, and technology data to investigate human adaptation. An NSF workshop identified a number of historical "experiments" that could reduce uncertainty about the likely economic consequences of global change.

USDA will investigate agricultural links in a modeling effort. EPA has significant efforts planned for the United States and for the world. In this area, a clearer representation of the uncertainty of effects is necessary. Most studies have investigated scenarios of global change that reflect the middle range of potential change at a single future point. There is, in this work, extreme need for interdisciplinary linkages to identify uncertainties in the physical effects of climate change. As important, however, is the need to establish the uncertainty inherent in translating physical effects to effects of relevance to the economy and society.

These thrusts are reflected broadly across the program increases and redirections proposed for FY 1993. In addition to focused USGCRP projects, five agencies have contributing projects that support the economics program mentioned above. Together these projects will support a balanced and integrated program of research carried out by the DOC, DOD, DOE, DOI, EPA, NSF and USDA. The funding levels for focused USGCRP and contributory agency projects are presented in Tables 2 and 3.

Table 2
FY 1990–93 Focused Budget for Economics Research Related to Global Change
(Dollars in Millions)

	1990	1991	1992	1993
Agency Totals	1.0	2.5	4.7	12.7
DOC	0.0	0.0	0.5	2.0
DOD	0.0	0.0	0.0	0.0
DOE	0.0	0.0	0.0	4.0
DOI	0.0	0.0	0.0	0.0
EPA	0.0	0.0	0.0	0.0
HHS	0.0	0.0	0.0	0.0
NASA	0.0	0.0	0.0	0.0
NSF	0.4	1.9	3.4	6.0
Smithsonian	0.0	0.0	0.0	0.0
TVA	0.0	0.0	0.0	0.0
USDA	0.6	0.6	0.8	0.7

Table 3
FY 1990–93 Contributory Budget for Economics Research Related to Global Change
(Dollars in Millions)

	1990	1991	1992	1993
Agency Totals	2.3	2.3	6.8	4.7
DOC	0.1	0.0	0.1	1.0
DOD	0.1	0.5	0.2	0.2
DOE	0.4	1.0	4.4	0.3
DOI	0.2	0.2	0.0	0.5
EPA	1.5	0.6	2.1	2.7
HHS	0.0	0.0	0.0	0.0
NASA	0.0	0.0	0.0	0.0
NSF	0.0	0.0	0.0	0.0
Smithsonian	0.0	0.0	0.0	0.0
TVA	0.0	0.0	0.0	0.0
USDA	0.0	0.0	0.0	0.0

Budget by Science Element

Table 4 and Figure 3 show the USGCRP budget by science element. While the Program maintains an appropriate level of effort in all seven science elements consistent with the policy needs, scientific priorities identified by the IPCC 1990 science and impacts assessments, and the current state of both national and international (WCRP and IGBP) scientific program development, the proposed FY 1993 activities focus primarily on the three highest priority science elements.

Budget by Scientific Objective

Table 5 and Figure 4 show the USGCRP budget by scientific objective. The proposed FY 1993 USGCRP Budget reflects (1) a balance between each of the scientific objectives; (2) a continued commitment to both establish an integrated, comprehensive (space- and ground-based) atmosphere, ocean, and terrestrial observing system, which will acquire the long term data bases necessary for the development and testing of predictive models and for global change monitoring, and to conduct focused studies to improve the understanding of key processes that control the global Earth system; and (3) a strong commitment to an augmentation in climate modeling and prediction.

Budget by Agency

Tables 4 and 5 and Figure 5 show the USGCRP budget by agency. The individual agency efforts build upon their respective scientific and technical strengths. Table 6 shows the budgets for programs that contribute to global change research and provide important support to the Program objectives but were initiated for reasons other than the focused Program goal.

Department of Commerce/National Oceanic and Atmospheric Administration. In FY 1993, NOAA has proposed a $78.2 million Climate and Global Change Program in support of the USGCRP. This represents a $31.2 million or 66 percent increase over FY 1992 appropriation. The FY 1993 NOAA contribution involves enhancements to ongoing efforts in: operational *in situ* and satellite observation programs with an emphasis on oceanic and atmospheric dynamics (including sea level), circulation, and chemistry; the development of new

Table 4
FY 1992–1993 U.S. Global Change Research Program Focused Budget by Science Element
(Dollars in Millions)

	Total Budget		Climate & Hydrologic Systems		Biogeo-chemical Dynamics		Ecological Systems and Dynamics		Earth System History		Human Interactions		Solid Earth Processes		Solar Influences	
	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993
Agency Totals	1,109.8	1,372.4	505.5	629.2	288.0	333.2	152.8	240.4	19.3	23.4	16.8	25.9	108.6	105.2	18.8	15.1
DOC/NOAA	47.0	78.2	38.5	65.1	5.0	6.3	0.9	2.4	2.1	2.4	0.5	2.0	0.0	0.0	0.0	0.0
DOD	6.3	6.6	3.8	4.0	0.9	1.1	1.0	1.0	0.3	0.2	0.0	0.0	0.3	0.3	0.0	0.0
DOE	77.0	113.0	59.3	85.9	11.0	16.5	5.8	6.0	0.0	0.0	0.9	4.6	0.0	0.0	0.0	0.0
DOI	39.4	35.8	12.8	9.5	3.1	2.8	8.2	8.8	8.1	7.3	2.3	2.6	4.9	4.8	0.0	0.0
EPA	24.0	26.0	0.0	0.0	14.4	15.5	8.6	9.5	0.1	0.1	0.9	0.9	0.0	0.0	0.0	0.0
HHS	1.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.2	0.0	0.0	0.0	0.0
NASA	755.9	890.8	351.1	404.3	212.0	246.5	85.9	143.8	0.0	0.0	0.0	0.0	92.9	88.7	14.0	7.5
NSF	108.5	162.5	37.2	56.9	29.1	38.7	13.4	25.4	7.7	11.7	6.8	12.0	9.6	10.3	4.7	7.5
Smithsonian	6.3	10.6	0.0	0.0	0.3	1.1	3.5	6.1	0.7	1.4	0.8	0.8	0.9	1.1	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	44.3	47.6	2.7	3.4	12.2	4.7	25.5	37.4	0.3	0.3	3.6	1.8	0.0	0.0	0.0	0.0

Figure 3

U.S. Global Change Research Program Budget by Science Element

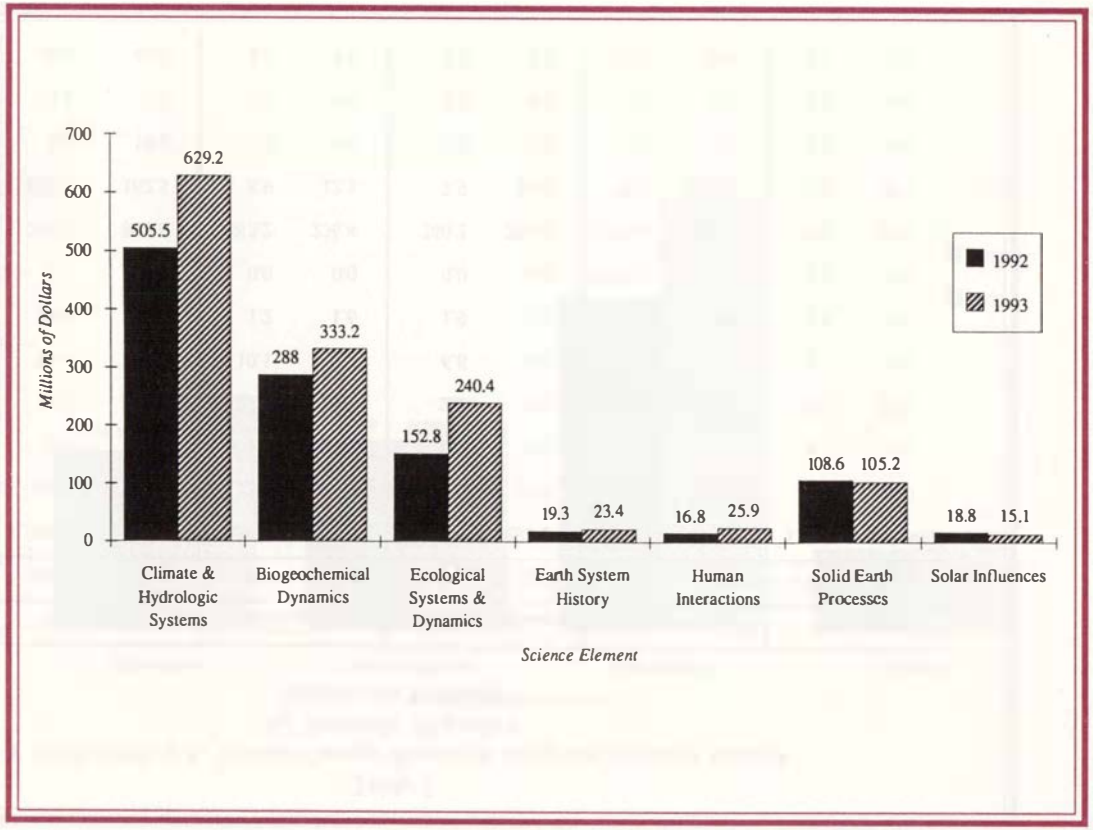


Table 5
FY 1992–1993 U.S. Global Change Research Program Focused Budget by Scientific Objective (Dollars in Millions)

	Total Budget		Observations		Data Management		Understanding		Prediction	
	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993
Agency Totals	1,109.8	1,372.4	254.1	328.6	269.6	295.2	468.3	606.1	117.8	142.5
DOC/NOAA	47.0	78.2	12.2	21.5	7.0	12.9	18.5	25.8	9.3	18.0
DOD	6.3	6.6	1.0	1.2	0.5	0.5	3.7	3.8	1.1	1.1
DOE	77.0	113.0	27.0	35.3	2.0	3.5	24.8	50.1	23.2	24.1
DOI	39.4	35.8	10.1	8.7	6.6	6.9	19.0	17.6	3.7	2.6
EPA	24.0	26.0	1.2	1.6	1.9	1.9	16.4	15.8	4.5	6.7
HHS	1.0	1.2	0.0	0.0	0.0	0.0	1.0	1.2	0.0	0.0
NASA	755.9	890.8	183.2	236.4	240.2	256.4	276.4	335.3	56.1	62.7
NSF	108.5	162.5	8.9	12.1	7.9	10.0	78.2	117.3	13.5	23.1
Smithsonian	6.3	10.6	2.3	4.0	0.6	0.8	3.1	5.2	0.3	0.6
TVA	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0
USDA	44.3	47.6	8.2	7.8	2.9	2.3	27.1	33.9	6.1	3.6

Figure 4

U.S. Global Change Research Program Budget by Scientific Objective

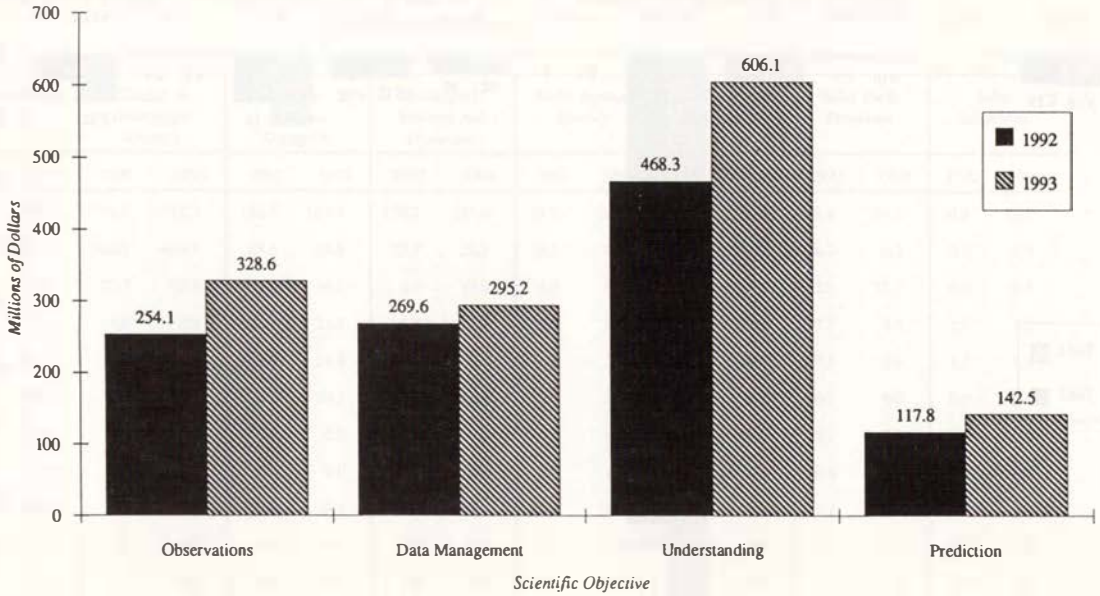


Figure 5

U.S. Global Change Research Program Budget by Agency

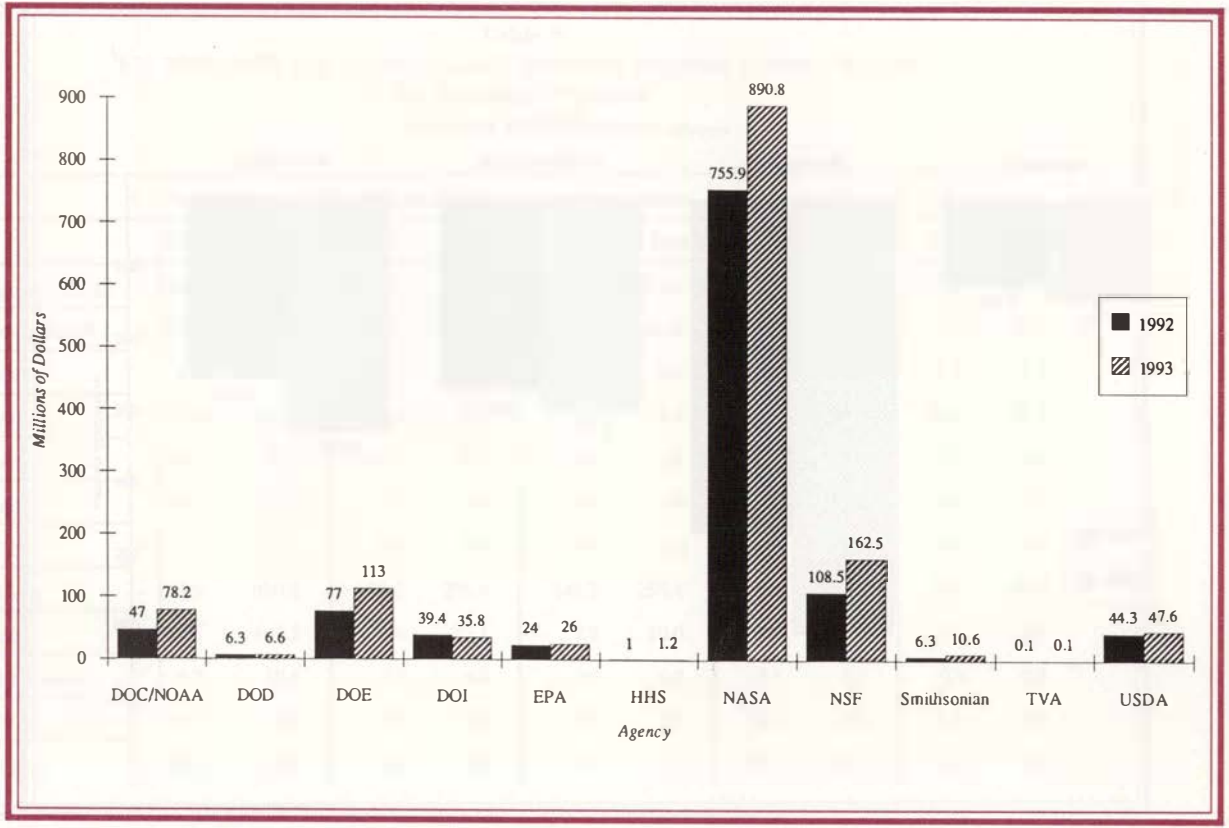


Table 6
FY 1992–1993 Budget of Contributory Programs to the U.S. Global Change Research Program
(Dollars in Millions)

	Total Budget		Climate & Hydrologic Systems		Biogeo-chemical Dynamics		Ecological Systems and Dynamics		Earth System History		Human Interactions		Solid Earth Processes		Solar Influences	
	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993
Agency Totals	1,301.7	1,390.6	710.5	715.3	158.0	189.9	179.7	217.0	28.9	29.1	170.4	173.8	43.4	54.4	10.8	11.1
DOC/NOAA	565.7	536.5	510.1	480.9	18.6	18.6	25.7	25.7	0.3	0.3	3.9	3.9	6.2	6.2	0.9	0.9
DOD	28.9	109.0	22.7	62.5	1.1	16.0	3.9	19.0	0.0	0.0	0.0	0.0	1.2	11.5	0.0	0.0
DOE	42.2	49.7	0.0	0.0	25.0	31.8	6.5	6.5	0.0	0.0	2.0	2.0	7.7	8.4	1.0	1.0
DOI	249.5	241.3	99.2	88.5	53.7	54.6	0.0	0.0	1.0	1.0	86.4	88.0	7.5	7.5	1.7	1.7
EPA	79.9	110.1	11.9	13.4	21.3	29.1	46.7	67.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HHS	45.2	46.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	45.2	46.6	0.0	0.0	0.0	0.0
NASA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NSF	143.7	149.8	50.4	52.8	27.1	28.6	25.1	26.4	25.8	26.0	5.1	5.5	5.1	5.1	5.1	5.4
Smithsonian	8.0	8.0	0.0	0.0	0.0	0.0	7.0	7.0	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0
TVA	7.5	8.5	7.5	8.5	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	131.1	131.1	8.7	8.7	11.2	11.2	64.8	64.8	1.3	1.3	27.3	27.3	15.7	15.7	2.1	2.1

measurement techniques; focused research on ocean-atmosphere interactions, the global hydrologic cycle, the role of oceanic circulation and biogeochemical dynamics in climate change, atmospheric trace gas/climate interactions, and the response of marine ecosystems and living resources to climate change and related stresses; and programs to improve climate modeling, prediction and information management capabilities. In addition, NOAA will contribute to the evolving interagency program of global change economics research.

Department of Defense. In FY 1993, DOD has proposed a $6.6 million budget for global change research, a 5% increase over the FY 1992 enacted level. This research is directed toward science areas where DOD has unique capabilities that concurrently satisfy Defense mission requirements and USGCRP goals. Programs in five basic research themes are supported: ocean measurements, high latitude dynamics, regional resolving models, boundary layer dynamics, and ecological system dynamics.

Department of Energy. In FY 1993, DOE has proposed a $113.0 million global change research budget, a $36.0 million or 47% increase above FY 1992 levels. The DOE maintains a research program directed at the impact of energy production and use on the global Earth system by focusing primarily on the climate response. DOE will continue research on climate modeling; carbon sources and sinks; impacts on ecosystems; critical data needs for early detection of climatic change; and funding for education and training of the future scientists/researchers in global change. A new effort will apply remotely piloted aircraft (RPAs) and small satellites to climate system change research problems, e.g., the cloud-climate feedback to atmospheric radiative balance.

Department of Health and Human Services/National Institute of Environmental Health Sciences. In FY 1993, NIEHS has proposed a budget of $1.2 million for research related to the health effects of global change, an increase of 20% above the comparable FY 1992 level. NIEHS funding supports research on health effects of CFC replacement chemicals and ultraviolet radiation. Studies include the metabolism and toxicity of HCFCs and halogenated hydrocarbons, effects of UV exposure on the pathogenesis of disease, repair of solar UV radiation related DNA damage in human cells, and effects of shorter wavelength UV radiation on photosensitivity in people who use many commonly prescribed drugs.

Department of the Interior. In FY 1993, DOI has proposed a $35.8 million budget for global change research, a decrease of $3.6 million from the FY 1992 enacted level of $39.4 million. DOI efforts include studies of: paleoclimates; interaction and sensitivity of hydrologic and ecological systems with climate at the local, landscape, and regional level; arid, polar, and coastal regions and systems; volcano-atmosphere interactions; methane hydrates; changing land surface characteristics; ocean heat fluxes; assessments of impacts of global change on natural resources and their social, environmental, and economic consequences; water resources, coastal wetland inundation, biological species and ecological systems characteristics and dynamics, and land management; and carbon cycle variation studies; as well as archiving and distributing space- and land-based Earth science data.

Environmental Protection Agency. In FY 1993, EPA has proposed $26.0 million for global change research, an increase of $2.0 million or 8% over the FY 1992 level. EPA's research efforts are focused on evaluating the processes and quantifying the relative contributions of anthropogenic and biological sources of trace gases, quantifying and modeling the consequences of climate change on ecosystems and their subsequent feedback to the atmosphere, and the interaction of trace gases in the atmosphere. Special emphasis will be given to climate sensitive regions, e.g., tundra and forests. EPA's research will help provide the process-level understanding and modeling capabilities to predict global change effects and feedbacks at the regional scale, as well as to put global climate change in a relative risk context.

National Aeronautics and Space Administration. In FY 1993, NASA has proposed $890.8 million for global change research, an increase of $134.9 million or 18% over the FY 1992 level. NASA research efforts are primarily focused on space-based studies of the Earth as an integrated system. These activities include ongoing research and satellite programs (such as the Upper Atmosphere Research Satellite and the Ocean Topography Experiment) that are important precursors to the Earth probes (a series of focused satellite missions designed to measure parameters such as atmospheric ozone, ocean surface winds, and precipitation in the tropics), and the Earth Observing System (EOS). This space-based activity is integrated with NASA's ongoing ground-based research programs in the observation, understanding, and modeling of

radiation, dynamics and hydrology; ecosystem dynamics and biogeochemical cycles; atmospheric chemistry; and solid earth science.

National Science Foundation. In FY 1993, NSF has proposed $162.5 million for global change research, an increase of $54.0 million or 50% above the FY 1992 level. NSF proposes to augment and initiate programs coordinated internationally to observe, understand, and model atmospheric, oceanic, terrestrial, polar, and social processes and their coupled interactions. Studies include ocean circulation, glacial dynamics, ocean-atmosphere interactions, cloud-radiation, global atmospheric chemistry, biogeochemical processes, land-sea interactions, past climate change, crustal and related processes impacting global change, ecosystems, solar processes, human dimensions of global change, data bases, and climate system modeling and prediction. NSF also has assumed a leading role in facilitating research on the economics of global change.

Smithsonian Institution. In FY 1993, SI has proposed a $10.6 million budget for global change research, a $4.3 million or 68% increase above FY 1992 levels. The Smithsonian's research concentrates on long-term documentation of ecosystem response to environmental change. SI efforts involve enhancements to ongoing research in tropical forest ecosystem dynamics, characterization and quantification of biological diversity, terrestrial and marine ecosystem response to global climate, atmosphere-ecosystem exchange, past climate change and ecosystem response, human dimensions of global change and quantitative documentation of global volcanism and other natural components of global change.

United States Department of Agriculture. In FY 1993, USDA has proposed $47.6 million for global change research, an increase of $3.3 million or 8% above the FY 1992 level. USDA research efforts are ground-based and focused on understanding terrestrial systems. USDA's programs emphasize studies of the effects of global change variables (such as water balance, atmospheric deposition, plant responses to changes in atmospheric constituents, and UV-B radiation) on agricultural, forest, and range ecosystems. Some representative studies that will focus on the potential agricultural effects on environmental variables will include effects of terrestrial ecosystems on water and energy fluxes to the atmosphere; mechanisms of methane generation and nitrous oxide release;

soil properties including moisture, erosion, organic matter dynamics, nutrient fluxes, and microbes; relationship of global change to forest and range fires, insects, and plant pathogens; and agricultural management systems. USDA will also provide ground truth for calibrating certain EOS satellite measurements.

Budget by Federal Budget Function

Scientific, environmental, energy, safety and security, and agricultural resources are vital to the health of all nations. Table 7 shows the USGCRP budget by Federal budget function. In FY 1993, significant increases above FY 1992 levels are proposed for most budget functions. The USGCRP must be viewed as a single integrated research effort where its success is dependent upon cooperation and contributions from each of the individual agency programs as well as with other nations and international programs.

Table 7
FY 1992–1993 U.S. Global Change Research Program Budget by Budget Function (Dollars in Millions)

Budget Function	Budget Function Number	1992	1993
TOTAL		1,109.8	1,372.4
National Defense (DOD)	050	6.3	6.6
General Science, Space and Technology	250	864.4	1,053.3
NASA		755.9	890.8
NSF		108.5	162.5
Energy	270	77.1	113.1
DOE		77.0	113.0
TVA		0.1	0.1
Natural Resources and Environment	300	110.4	140.0
DOC/NOAA		47.0	78.2
DOI		39.4	35.8
EPA		24.0	26.0
Agriculture (USDA)	350	44.3	47.6
Smithsonian	503	6.3	10.6
Health (HHS/NIEHS)	550	1.0	1.2

Areas Needing Special Emphasis

Data and Information Management

The global scale and long-term nature of global change processes requires that continuous observations from many national and worldwide sources be used synergistically with existing data to achieve scientific understanding and for the ultimate attainment of a predictive capability. This requires careful arrangements for managing the wide range and enormous volumes of data and information which will result from the space- and ground-based observational programs. Because of the critical importance of data and information management in achieving the scientific objectives, this aspect of the USGCRP has been emphasized strongly throughout the entire program life cycle. In addition, the U.S. will continue to work closely with other nations and international organizations to develop and implement the additional observational programs and data management processes needed to ensure that the necessary data is available to scientists working on global change research in many nations throughout the world.

Success of the USGCRP will depend upon open access for the scientists to the full suite of data and information needed for their research. CEES has developed a set of data management principles addressing continuing agency commitment to the production and preservation of high quality, long-term data sets, data exchange standards, data access, and maintaining the lowest possible cost of data for research purposes. These fundamental principles are embodied within the USGCRP planning. The seven principles, adopted by the Administration as policy, are listed below.

- The Global Change Research Program requires an early and continuing commitment to the establishment, maintenance, validation, description, accessibility, and distribution of high-quality, long term data sets.

- Full and open sharing of the full suite of global data sets for all global change researchers is a fundamental objective.

- Preservation of all data needed for long-term global change research is required. For each and every global change data parameter, there should be at least one explicitly

designated archive. Procedures and criteria for setting priorities for data acquisition, retention, and purging should be developed by participating agencies, both nationally and internationally. A clearinghouse process should be established to prevent the purging and loss of important data sets.

- Data archives must include easily accessible information about the data holdings, including quality assessments, supporting ancillary information, and guidance and aids for locating and obtaining the data.

- National and international standards should be used to the greatest extent possible for media and for processing and communication of global data sets.

- Data should be provided at the lowest possible cost to global change researchers in the interest of full and open access to data. This cost should, as a first principle, be no more than the marginal cost of filling a specific user request. Agencies should act to streamline administrative arrangements for exchanging data among researchers.

- For those programs in which selected principal investigators have initial periods of exclusive data use, data should be made openly available as soon as they become widely useful. In each case, the funding agency should explicitly define the duration of any exclusive use period.

The primary data management focus of the FY 1993 program is to take initial steps to ensure that existing and emerging key data sets are preserved and made more readily accessible. Eight agency data management proposals are identified as being of critical importance to this end.

- For NASA's Earth Observing System Data and Information System (EOSDIS), a set of early Earth science data and information activities will concentrate on the improved use of existing data sets within the initial years, in advance of receipt of the larger capabilities required to handle the data flow from the full suite of EOS instruments. The EOS 1993 budget will make this early work possible while, at the same time, beginning the build-up toward the full EOS capability.

- The DOE's Information/Coordination Program will improve access to, and use of, the Carbon Dioxide Information Analysis Center. This includes updating and maintaining the baseline carbon dioxide emissions data set, producing numeric data packages on trace gas emissions and concentrations, and updating publications to provide current information on climate and on emissions and concentrations of trace gases.

- The DOI/USGS Land Data Program will provide improved access to space- and ground-based land data for global change research. In FY 1993, this will include continued operation of the Global Land Information System; continuing conversion of Landsat Thematic Mapper data to a stable storage medium; and developing and distributing global land data sets, beginning with satellite-derived vegetation index data and soils data for North America.

- The Mission Operations and Data Analysis Program of NASA provides for the acquisition, processing, and archiving of long-term data sets produced by ongoing spaceborne missions. Missions covered by this proposal include the Total Ozone Mapping Spectrometer (TOMS), the Solar Backscatter Ultraviolet (SBUV), the Stratospheric Aerosol Measurement (SAM-II), the Stratospheric Aerosol and Gas Experiment (SAGE-2), the Earth Radiation Budget Experiment (ERBE), the Alaska Synthetic Aperture Radar (SAR) Facility (ERS-1 and JERS), the Shuttle Imaging Radar (SIR-C), the Upper Atmosphere Research Satellite (UARS), and the Ocean Topography Experiment (TOPEX/Poseidon).

- NOAA, in its Information Management Systems Program, supports improvements to its data holdings in order to meet the needs of the USGCRP. In 1993, this will include steps toward assembling and preparing widely-dispersed data holdings to form useful and cohesive long-term data bases, and toward addressing quality assurance, archival, and access problems for *in situ* and satellite data within NOAA's National Climate, Geophysical, and Ocean Data Centers.

- NOAA's Operational Measurements Program covers a number of NOAA activities which facilitate use of the operational satellite data and complement the other-agency

programs. These include developing and providing information products from NOAA's operational satellites which will be used collectively with EOSDIS products.

- The NSF Geosystems Databases Program will increase in FY 1993 to broaden existing projects to better meet the interdisciplinary needs of the USGCRP. These include exploratory research on value-added data and information products, such as model-assimilated information, the development of long-term data sets for studying global change, and research on managing very large data sets. NSF will strengthen the data management infrastructure available to its global change scientific communities, for example through enhanced mass storage and retrieval capabilities for model data outputs.

- USDA's Clearinghouse for Global Change Information will provide one-stop access to the Department's geographic information systems, long-term records from experiment stations, national agricultural and economics statistics, research data bases pertinent to USGCRP in forestry and agriculture, and national and international soil data bases. The first phase will be the development of special directories to information sources.

In addition to these major data-intensive activities, most research programs include a substantial data management and analysis component directed toward the preparation and dissemination of data and information from those individual programs. These activities are also essential in making the broad range of new data and information easily usable for national and international global change research.

Space-Based Research

The proposed level of funding for space-based research programs in FY 1993 is $456.7 million (NASA and DOE); an increase of $79.6 million or 17 percent over the FY 1992 level. The proposed level of funding for the Earth Observing System (observatories, instruments, and scientific investigations) in FY 1993 is $308.4 million, an increase of $120.0 million over the FY 1992 level.

Maintaining an appropriate balance between ground- and space-based research programs is essential for a successful USGCRP. *In situ* and theoretical studies of physical, chemical, biological and geological processes must be complemented by a comprehensive space-based program to provide the global observations of key environmental variables. In many, if not most cases, there simply is no other way to provide truly global measurements in a scientifically consistent and rigorous way over a long enough time to distinguish natural variability from human-driven changes. The combination of ground- and space-based measurements is necessary, given the temporal and spatial variability of the systems being studied and the need to scale the processes occurring at the local scale to regional and global scales. The ground-based program is essential to interpret some of the global satellite observations as well as obtain scientific information not measurable from space (e.g., trace gas fluxes). In addition, *in situ* experimental studies on key processes provide confirmation of hypotheses derived from larger-scale observations. Both types of programs need to be strongly supported.

In FY 1993, the CEES, with strong NASA participation and the advice of the scientific community, will begin to coordinate the development of a space-based observing system for global change. The space-based component of the USGCRP is being expanded in FY 1993 to include contributions from DOD and DOE, in addition to the primary role played by NASA.

The proposed NASA space-based program is responsive to scientific and policy needs. The NASA space-based program includes: (1) Mission to Planet Earth Phase I missions, such as the Upper Atmosphere Research Satellite (UARS), launched in September 1991, and already providing the first global observations of the chemical species involved in the destruction of stratospheric ozone, and TOPEX/Poseidon to study ocean circulation and the oceanic redistribution of heat; (2) a series of Earth Probes, including a Total Ozone Mapping Spectrometer (TOMS) to measure atmospheric ozone, a scatterometer (NSCAT) to measure ocean surface winds, a Tropical Rainfall Measurement Mission (TRMM) to measure precipitation in the tropics; (3) Mission Operations and Data Analysis of satellite and shuttle experiments, including the current TOMS and ERBE data, data from European and Japanese synthetic aperture radar, and the planned ocean-color data set; and (4) EOS,

which will provide an integrated monitoring program of measurements of key climate change variables, coupled with a comprehensive data and information system. EOS was initially designed to provide a comprehensive set of measurements on many different aspects of global change. In response to both the Administration and Congressional concern over the costliness and engineering feasibility of EOS, an external engineering review committee, chaired by Dr. Edward Frieman, was convened to determine the feasibility of alternative implementation approaches to reduce program funding requirements and increase the resiliency and flexibility of EOS. As a result, NASA is well on its way toward implementing a restructuring of EOS which emphasizes studies of global climate change while making only limited observations of stratospheric chemistry and solid Earth geophysics. The scientific priorities for the EOS restructuring were based on the scientific uncertainties identified by the IPCC assessment process. Based on the Frieman Committee's findings, an interagency working group has been formed by the National Space Council to formulate and coordinate the implementation of an Administration policy directive.

The proposed EOS consists of three medium-sized platforms, compatible with launch on an Atlas IIAS vehicle. As before, each spacecraft will fly in sun-synchronous polar orbits, but with different crossing times — one AM and two PM. The EOS AM-crossing and PM-crossing spacecraft will be repeated twice on five-year centers for at least fifteen years' data coverage, in order to provide long-term continuity of observations. In addition, the program includes two series of smaller spacecraft, one dedicated to precision altimetry and the other providing for occultation measurements from non-synchronous orbit. The restructured EOS also includes an extension of the ocean color data purchase and contribution of Earth radiation budget and lightning instruments for flight on TRMM and its follow-ons.

The AM platform will contain the following instruments, primarily required for imaging the land surface, providing atmospheric corrections, and responding to the IPCC priorities on climate and hydrologic systems, greenhouse gases, and radiation balance: Advanced Spaceborne Thermal Emission and Reflection (ASTER); Multi-Angle Imaging Spectro-Radiometer (MISR); Moderate-Resolution Imaging Spectrometer - Nadir (MODIS-N); Measurements of Pollution in the

Troposphere (MOPITT); and Clouds and the Earth's Radiant Energy System (CERES). The AM platform is planned for launch in June 1998.

The PM platform will contain the following instruments, primarily required for atmospheric soundings of temperature, water vapor, and radiation balance, and responding primarily to the IPCC priorities on clouds and radiative balance and greenhouse gases: Atmospheric Infrared Sounder (AIRS); Advanced Microwave Sounding Unit (AMSU-A); Microwave Humidity Sounder (MHS); Multifrequency Imaging Microwave Radiometer (MIMR); CERES and MODIS-N. The PM platform is scheduled for launch in late 2000.

The second PM platform will contain the following instruments, primarily required for measuring atmospheric composition and sea surface winds and responding to the IPCC priorities on greenhouse gases and climate hydrologic systems: Tropospheric Emissions Spectrometer (TES); High-Resolution Dynamics Wind Sounder (HIRDLS); Stratospheric Aerosol Gas Experiment-III (SAGE III); Stick Scatterometer (STIKSCAT).

Future platforms may have changes in the complement of instruments in order to respond both to advances in instrument technology and scientific advances. For example, NASA plans to launch the High Spectral Resolution Imaging Spectrometer (HIRIS) on the second AM platform, replacing part or possibly all of ASTER. However, the continuity of global measurements from space remains a high priority. In addition, NASA's EOS program depends more strongly on collaboration with foreign partners, including the European Space Agency and Japan.

Environmental data from the Landsat series of satellites are particularly suited to the long-term estimation and monitoring of key environmental parameters, including vegetation, biological productivity, land cover type, snow and ice, desertification, and changes in fragile ecosystem borders. Many of these changes are intrinsically linked to global climate change, both as an early indicator of climate change and as a contributor to changes in the chemical composition of the atmosphere. The 18 years of uninterupted Landsat data provide a unique baseline to monitor change and will not be available from any other space- or ground-based source, including NASA's EOS program.

The Administration is committed to the continued acquisition of Landsat-type data for national security, global change research, and other Federal users needs and is proposing in FY 1993 to initiate the procurement of a Landsat 6 follow-on. DOD will be responsible for the procurement of the spacecraft and NASA will be responsible for data acquisition and distribution.

The FY 1993 USGCRP is proposing $25 million for NASA's Landsat data acquisition and distribution activities related to global change research. Although DOD will benefit from Landsat-related global change research, the DOD's primary interest in Landsat data continues to be for national security purposes. Thus, the DOD funding ($80 million) for the procurement of a Landsat 6 follow-on is being considered as contributing and not part of the focused USGCRP, much like the operational weather satellites in DOC/NOAA.

DOE plans to develop a program of small Earth radiation budget satellites to complement the NASA Earth Probes and EOS programs. This extension of the space-based component of the USGCRP is intended to augment the satellite data streams in the mid-1990s and contribute to the goal of implementing the Earth radiation budget element of a Global Climate Observing System on an earlier schedule.

International Dimensions

The international global research aspects of the USGCRP are actively coordinated with those of other countries through a broad range of international arrangements. U.S. scientists work directly and very closely with their foreign counterparts in the planning of specific global change research programs of the WCRP such as TOGA, WOCE and GEWEX; core projects of the IGBP such as JGOFS and IGAC; UNESCO's Man and the Biosphere (MAB) Program to use MAB Biosphere Reserves as global change research sites; and emerging national and international programs in the human dimensions of global environmental change, particularly global change economics research.

As these programs move from planning towards implementation, leadership for oversight and coordination shifts somewhat to intergovernmental organizations which, in concert with

the International Council of Scientific Unions (ICSU), are uniquely able to assist in broadening participation in and governmental support for global change research, particularly in developing countries. These organizations include the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission (IOC), and the United Nation's Environment Programme (UNEP). The U.S. shares in funding these program coordination activities through related U.S. national programs, augmented in some cases by direct funding of specific coordinating activities (e.g., the Scientific Committee for Oceanic Research (SCOR) of ICSU).

The U.S. agencies which fund global change research are also developing direct links with funding agencies in other countries, most notably on a multilateral basis through the informal International Group of Funding Agencies for Global Change Research (IGFA). Through this Group, the funding agencies discuss issues of common interest, including the identification of research gaps; the availability of facilities support such as ships and aircraft; and the development of mutually supportive national contributions to international global change research projects.

The USGCRP for FY 1993 continues efforts to create global change research institutes, particularly to address regional implications of global change in economically developing countries. The President introduced this concept at the White House Conference on Science and Economics Research Related to Global Change at which he invited other countries to join the United States in developing this initiative. Following the President's trip to Latin America in December 1990 which provided an opportunity to advance this initiative, active discussions directed at establishment of a global change research institute for the Western Hemisphere have been undertaken and plans are being developed with the objective of establishing an Inter-American Institute for Global Change Research during the next year. Detailed discussions with interested countries will continue during 1992 under the leadership of the White House Office of Science and Technology Policy and the CEES. Additional efforts will be directed to foster establishment of other regional institutes for global change research.

The funding by which the CEES agencies support such international coordination activities is provided through the

specific national programs involved and, thus, are commensurate with the needs of each U.S. national program. Requests for such funding are reviewed by each agency in accordance with its normal review process. It is estimated that the U.S. provides slightly less than one-half of the total costs of these international coordination activities and that this percentage is decreasing steadily as more countries become directly involved in global change research.

Program Management and Evaluation

The CEES has initiated a comprehensive effort to develop and implement an overall coordination, program evaluation, and management strategy for the USGCRP. While recognizing agencies' responsibilities to implement individual projects, this strategy fosters a process of collaboration focused on measuring progress, identifying gaps and assessing the effectiveness of agency activities. The management strategy takes a cooperative approach to providing high priority global change predictions, assessments, and related information. Under such a management arrangement, meaningful performance measures for major elements of the Program will be developed and tracked, providing periodic evaluations of both individual projects and the USGCRP as an integrated effort. The anticipated management strategy will provide for continued evolution of the USGCRP in response to new scientific insights and future developments in national and international scientific planning efforts (e.g., the NAS Committee on Global Change, IGBP and the WCRP). CEES plans also call for a management strategy which enhances the ability of the CEES to provide information on the status of the USGCRP as well as summaries of the state of scientific understanding on key components of the Earth System on a routine basis. Such a mechanism will improve the Committee's ability to serve the near-term needs of decision makers while establishing the long-term scientific foundation for national and international global change policy formulation. The management strategy will be fully implemented during FY 1992-93.

Remotely Piloted Aircraft

Several immediate research needs can be uniquely met by Remotely Piloted Aircraft (RPA) using existing or light-weight derivative instrumentation. RPAs can address several critical issues that cannot be adequately addressed by any existing ground, aircraft, balloon, rocket, or satellite platforms. The flight characteristics needed involve enhanced duration (days to weeks) and high altitude (up to 30 km) with both light and heavy (up to 1500 kg) payloads. The RPAs offer the potential to obtain critical data on important Earth science processes in a unique and previously unexplored manner using *in situ* and remote sensing instrumentation at low costs. Areas of global change research that will be advanced by utilization of instrumented RPAs include, radiation studies; long-duration storm dynamics; ecosystem dynamics; meteorology; long-duration fire dynamics; polar and global ozone dynamics and chemistry; and stratospheric/tropospheric exchanges. The DOE budget includes $10 million to initiate, in cooperation with DOD, NASA, and NOAA, the modification and use of RPAs to conduct global change research.

Appendix

Fiscal Year 1992-1993 Global Change Research Program 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	FY 92	FY 93
DOC	NOAA	Global Sea Level	3.6	4.8
DOC	NOAA	Upper Ocean Observations	3.0	5.2
DOC	NOAA	Operational Measurements	4.1	9.8
DOC	NOAA	Measurement Technique Development	0.3	1.2
DOC	NOAA	Information Management	4.4	7.0
DOC	NOAA	TOGA	6.0	6.8
DOC	NOAA	Clouds, Energy, Water (GEWEX)	1.9	3.1
DOC	NOAA	Ocean Circulation/Biogeochemistry	5.9	9.2
		(WOCE & Atlantic Climate Change)	(2.4)*	(3.4)
		(Ocean CO_2/JGOFS & Marine Sulfur)	(2.3)	(3.7)
DOC	NOAA	Climate Modeling and Analysis	9.3	18.0
		(Near-Term Forecasting)	(0.6)	(2.2)
DOC	NOAA	Atmospheric Chemistry	5.0	6.3
DOC	NOAA	Marine Ecosystem Response	0.9	2.4
DOC	NOAA	Paleoclimate	2.1	2.4
DOC	NOAA	Economics Research	0.5	2.0
DOC		TOTAL	47.0	78.2
DOD	ONR	High Latitude Dynamics	2.7	2.4
DOD	ONR	Regional Resolving Models	1.0	1.0
DOD	ONR	Boundary Layer Dynamics	0.9	1.1
DOD	ONR	Ocean Ecological Dynamics	1.0	1.0
DOD	ONR	Ocean Measurements	0.2	0.6
DOD	CRREL	High Latitude Dynamics	0.3	0.3
DOD	CRREL	Regional Resolving Models	0.2	0.2
DOD		TOTAL	6.3	6.6

* Parentheses ( ) denote project subcomponent allocation.

Agency	Bureau	Project	FY 92	FY 93
DOE	OHER	Core CO_2 Research	17.9	17.9
DOE	OHER	CHAMMP - Computer Hardware, Advanced Math & Model Physics	10.5	12.1
DOE	OHER	Information/Coordination	2.0	2.2
DOE	OHER	National Institute for Global Environmental Change	11.0	9.0
DOE	OHER	Oceans Research	5.1	7.0
DOE	OHER	Quantitative Link	4.9	5.1
DOE	OHER	ARM - Atmospheric Radiation Measurements	23.2	31.9
DOE	OHER	Critical Data: First Detection	0.0	0.7
DOE	OHER	Education	2.4	3.1
DOE	OHER	Remotely Piloted Vehicles	0.0	10.0
DOE	OHER	Small Satellites	0.0	10.0
DOE	OHER	Economics	0.0	4.0
DOE		TOTAL	77.0	113.0
DOI	BIA	Uneven-Aged BIA Forests	0.1	0.1
DOI	BLM	Ecological Change in Environmentally Stressed Ecosystems of the Western & Northern U.S.	1.0	1.0
DOI	BOM	Methane Emissions from Coal Seams	0.1	0.1
DOI	BOR	Sensitivity of Hydrological Systems	1.3	1.1
DOI	BOR	Regional Studies	1.5	1.2
DOI	FWS	Coastal Wetland Change & Dynamics	1.3	1.1
DOI	FWS	Monitoring Fish & Wildlife Impacts	2.3	2.1
DOI	NPS	Integrated Studies of NPS Ecosystems	2.5	3.6
DOI	NPS	Dynamics of Coastal Systems	0.1	0.1
DOI	USGS	Paleoclimates	8.4	7.2
DOI	USGS	Land Characterization	2.0	2.0
DOI	USGS	Interaction of Climate & Hydrologic Systems	5.0	3.6
DOI	USGS	Biogeochemical Exchanges	1.1	0.8
DOI	USGS	Volcano Emissions	0.4	0.4
DOI	USGS	Sensitivity of Water Resources	1.5	0.3
DOI	USGS	Cold Regions Research	1.4	1.3
DOI	USGS	Coastal Erosion & Wetlands Prog.	3.0	2.9
DOI	USGS	Climates of Arid & Semi Arid Regions	0.9	0.9
DOI	USGS	Land Data	5.5	5.5

Agency	Bureau	Project	FY 92	FY 93
DOI	OS	Assessments of the Impacts on Natural Resources	0.0	0.5
DOI		TOTAL	39.4	35.8
EPA	ORD	Earth System Modeling Analysis	1.2	1.6
EPA	ORD	Effects of Global Changes on Rice Yields	2.3	2.3
EPA	ORD	North American Landscape Characterization	1.9	1.9
EPA	ORD	Monitoring Forest Conversion/ Biomass Burning	0.5	1.0
EPA	ORD	Anthropogenic Methane/RITG Emissions	3.0	3.0
EPA	ORD	Tropospheric Chemistry	3.0	3.0
EPA	ORD	Greenhouse Gas Pools & Fluxes in Terrestrial Ecosystems	1.6	1.6
EPA	ORD	Biospheric Carbon Pools & Fluxes	4.3	4.5
EPA	ORD	Climate-Induced Biospheric Feedbacks from Soils	0.8	0.8
EPA	ORD	Stratospheric Ozone Depleting Chemicals	0.9	0.9
EPA	ORD	Micro- to Macro-Scale Eco. Responses	4.5	5.4
EPA		TOTAL	24.0	26.0
HHS	NIEHS	Human Health Effects of Increased Exposure to Shorter Wavelength UV	0.6	0.7
HHS	NIEHS	Human Health Effects of CFC Replacement Chemicals	0.4	0.5
HHS		TOTAL	1.0	1.2
NASA	OSSA	TOPEX-Ocean Topography Experiment	51.9	0.0
NASA	OSSA	Payload & Instrument Development	48.6	49.4
NASA	OSSA	Earth Observing System (EOS)	188.4	308.4
NASA	OSSA	Earth Probes	88.2	88.9
NASA		Space-based Subtotal	377.1	446.7

Agency	Bureau	Project	FY 92	FY 93
NASA	OSSA	Research & Analysis	200.1	174.2
NASA	OSSA	Mission Operations & Data Analysis	56.3	117.1
NASA	OSSA	EOS-Data Information Systems (EOSDIS)	82.6	82.6
NASA	OSSA	Suborbital Research Operations	20.3	22.9
NASA	OSSA	Construction of Facilities	17.0	22.3
NASA	OSSA	Landsat	2.5	25.0
NASA		Ground-based Subtotal	378.8	444.1
NASA		TOTAL	755.9	890.8
NSF	GEO	ARCSS-Arctic System Science	11.8	15.5
NSF	GEO	CHP-Continental Hydrologic Processes	1.0	1.0
NSF	GEO	CMAP-Climate Modeling, Analysis & Prediction	2.0	5.9
NSF	GEO	ROCEW-Role of Clouds, Energy & Water	0.6	1.9
NSF	GEO	TOGA-Tropical Oceans Global Atmosphere	13.5	17.4
NSF	GEO	WOCE-World Ocean Circulation Experiment	14.1	20.0
NSF	GEO	GTCP-Global Tropospheric Chemistry Program	11.6	14.4
NSF	GEO	JGOFS- Joint Global Ocean Flux Study	12.9	18.0
NSF	GEO	Ozone Depletion/UV Effects	5.6	5.6
NSF	GEO	Antarctic Ecosystems	1.5	1.5
NSF	BIO	EROC - Ecological Rates of Change	3.4	5.2
NSF	GEO	GLOBEC-Global Ocean Ecosystems Dynamics	2.7	7.4
NSF	BIO/GEO	LMER-Land-Margin Ecosystems Research	2.6	4.2
NSF	BIO	WEV-Water-Energy-Vegetation	0.1	1.2
NSF	GEO	Abrupt Climate Change	0.1	0.9
NSF	GEO	Geological Record of Global Change	1.9	3.9
NSF	GEO	Geological Record of Sea Level	0.0	1.5
NSF	SBE	Economics Research on Global Change	3.4	6.0

Agency	Bureau	Project	FY 92	FY 93
NSF	SBE	Human Dimensions of Global Change	3.4	4.8
NSF	GEO	Geodynamics	5.7	7.5
NSF	GEO	RIDGE-Ridge Interdisciplinary Global Experiment	3.7	4.1
NSF	GEO	CEDAR-Coupling, Energetics, & Dynamics of Atmospheric Regions	4.5	5.2
NSF	GEO	GEM-Geospace Environment Modeling	0.2	1.5
NSF	GEO	SunRISE-Radiative Inputs of the Sun to Earth	0.0	0.8
NSF	GEO	Geosystems Databases	2.0	1.9
NSF	GEO/BIO	Global Change Education & Training	0.2	0.2
NSF	GEO/BIO	International Institutes	(2.0)**	5.0
NSF		TOTAL	108.5	162.5

** Funding for International Institutes in FY 1992 is distributed across other NSF activities.

SI	NMNH	Tropical Biological Diversity Program	0.8	1.2
SI	NMNH	Tropical Coastal Ecosystems Program	0.4	0.3
SI	NMNH	Human Ecology History	0.3	0.4
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	1.8
SI	STRI	Tropical Forest Science Program	0.8	1.2
SI	STRI	Patterns of Change in East African Savanna Ecosystems	0.0	0.1
SI	STRI	Tropical Agroforestry Program	0.2	0.2
SI	SERC	Chesapeake Bay Global Change Research	0.6	1.5
SI	SERC	Temperate & Tropical Forest Canopy Biology	0.4	1.0
SI	NZP	Migratory Birds	0.3	0.3
SI	NZP	Predicting Species Responses	0.1	0.6

Agency	Bureau	Project	FY 92	FY 93
SI	SAO	Atmospheric Physics and Chemistry	0.2	0.7
SI	SAO	Solar Studies/Global Change	0.1	0.1
SI	SAO	Space Geodetic Sea Level Monitoring	0.1	0.1
SI	NASM	Global Change in Earth's Drylands	0.3	0.5
SI	IC	SI/MAB Biological Diversity Program	0.1	0.1
SMITHSONIAN		TOTAL	6.3	10.6
TVA	RBO	Regional Climate Impact Assessment	0.1	0.1
TVA		TOTAL	0.1	0.1
USDA	ARS	Biological Response to UV-B	0.7	0.0
USDA	ARS	Ecosystem Modeling	2.0	3.9
USDA	ARS	Biogeochemical Fluxes	2.0	2.8
USDA	ARS	Ozone Effects	0.4	0.0
USDA	ARS	Scale Effect of Hydro. Proc.	1.0	1.3
USDA	ARS	Pred. Impact on Sustain. Wtr	0.9	1.3
USDA	CSRS	Stratospheric Ozone Depletion	9.4	9.4
USDA	CSRS	UV-B Monitoring	2.0	3.0
USDA	CSRS	Methane Generation	0.0	1.0
USDA	SCS	Soil Climate	0.8	0.8
USDA	SCS	Soil Carbon/Soil Genesis	0.7	0.7
USDA	FS	Atmosphere/Biosphere Gas & Energy Exchange	7.9	7.6
USDA	FS	Ecological System Dynamics	9.0	10.7
USDA	FS	Disturbance Ecology	3.9	3.3
USDA	FS	Integrating Human Activities & Natural Resources	2.8	1.1
USDA	ERS	Econ. Sys. & Global Change	0.8	0.7
USDA		TOTAL	44.3	47.6

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	OSSA	Office of Space Science & Applications
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

The upper right figure provides a view of the Earth's biosphere. Shown is a three-year composite image of ocean chlorophyll concentration (increasing from purple to red) and land vegetation index (increasing from yellow to green), derived from NASA's Nimbus-7 Coastal Zone Color Scanner and the NOAA-7 Advanced Very High Resolution Radiometer (AVHRR), respectively.

The middle figure shows sea surface temperature for January 1984 (increasing from blue to red) measured by the NOAA-7 AVHRR. The relative coolness of the surface waters in the eastern boundary currents is clearly evident.

The lower left figure shows sea level variability (increasing from purple to red) measured by the U.S. Navy's GEOSAT over a two-year period. The image reveals fluctuations in the western boundary currents.

The U.S. Global Change Research Program