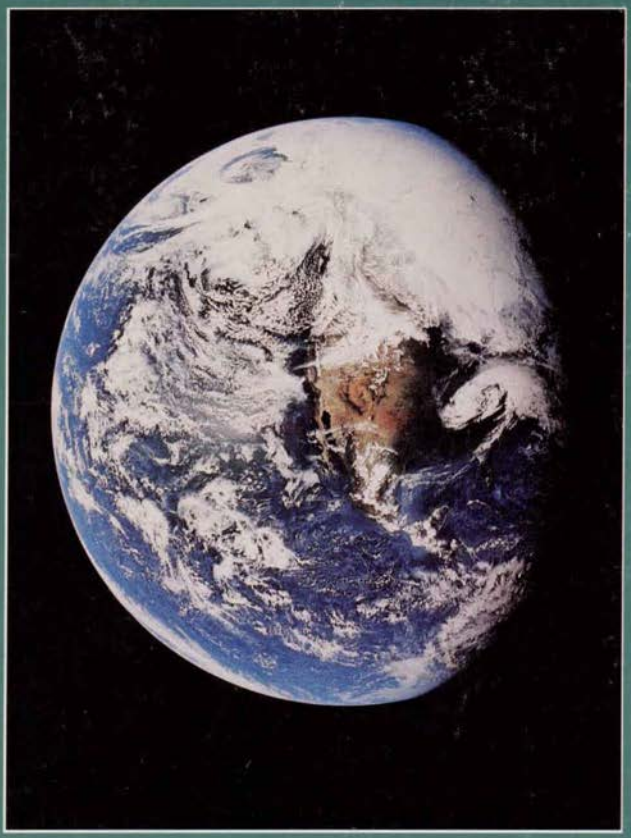
Our Changing Planet:

The FY 1992
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 1992 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.

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

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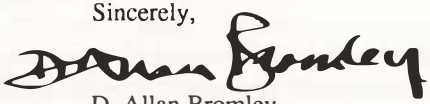
precipitation. The research program detailed in this report builds upon those described in the earlier reports in this series and, as such, will provide critical input to the negotiations on the Framework Convention on Climate Change, which are being initiatied here in Washington coincident with the release of this report.

The Committee on Earth and Environmental Sciences' 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. Dr. Dallas Peck, Chairman of the Committee on Earth and Environmental Sciences (CEES), Vice Chairmen Erich W. Bretthauer and Lennard A. Fisk, Dr. Robert W. Corell, Chairman of the CEES Working Group on Global Change, and their interagency committee members, associates, and staff have again done an excellent job and are to be commended.

Sincerely,



D. Allan Bromley
Director

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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 impacts on commerce, agriculture, energy, resource utilization and human safety.

- The central goal of the U.S. Global Change Research Program (USGCRP) is to establish the scientific basis in support of national and international policymaking relating 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;
  - Developing integrated conceptual and predictive Earth system models.

  This goal can best be achieved through cooperation with global change research activities of all nations and many organizations and programs.

- The highest priority scientific and policy-related issue for the USGCRP in FY 1992 is whether, and to what extent, human activities are changing, or will change, the global climate system.

- The FY 1992 USGCRP responds 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.

- Using the information needs identified by the IPCC, the USGCRP adopted four high priority Integrating Themes for FY 1992:

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

- The Integrating Themes allow the USGCRP to focus the collective efforts of government and academic scientists, in collaboration with scientists from other countries, on high priority, multi disciplinary investigations in order to:

  - Develop an improved predictive capability of the Earth as a coupled system with enhanced regional resolution;
  - Improve the understanding of the water and energy cycles by focusing on the role of clouds, oceans, terrestrial ecosystems, and changes in sea level;
  - Improve the understanding of the carbon cycle by quantifying sources and sinks, the processes that control them, and how the processes may influence and be influenced by global change;
  - Improve the capacity to assess the effects of global change at regional scales on intensively managed and natural terrestrial and oceanic ecosystems.

- The USGCRP also enhances support for economics research related to global change, and includes continued support for investigations in stratospheric ozone, human interactions, solid earth processes, and solar influences.

- The President's FY 1992 Budget requests $1186 million for the USGCRP. This represents an increase of $232 million, or 24.2 percent, over the FY 1991 level.

- 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

World leaders continue to debate the economic and social implications of global environmental changes, both natural and human-induced. The 1988 midwestern U.S. drought underscored the potential effects of a warm, dry summer, just as the climate of recent decades in the Sahel starkly reveals the human tragedy that can occur in marginal-subsistence zones of a changing planet. Furthermore, the linking of the antarctic ozone "hole" to man-made chlorofluorocarbons (CFC's) and the current debate over humanity's role in the "greenhouse effect" have placed the environment high on the national and international agenda. The substantial costs associated with addressing global environmental changes require policy decisions be based on adequate scientific and economic knowledge. In virtually all these issues, the salient feature is the significant scientific uncertainty associated with predicting the behavior of the coupled ocean-atmosphere-land Earth system. To reduce this uncertainty, the U.S. Global Change Research Program (USGCRP) has been developed as a central component of the U.S. Government's approach to global environmental change and its contribution to worldwide efforts.

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 and is driven by carefully established priorities that must be addressed to establish sound national and international policies related to global environmental issues, particularly global climate change.

The overarching and long-term goal of the USGCRP is to establish the scientific basis for national and international policymaking relating to natural and human-induced changes in the global Earth system.

To meet this goal, the CEES has established the following overall objectives for the USGCRP:

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

- To conduct a program of focused studies to improve our understanding of the physical, geological, chemical, biological, and social processes that influence Earth system processes and trends on global and regional scales; and

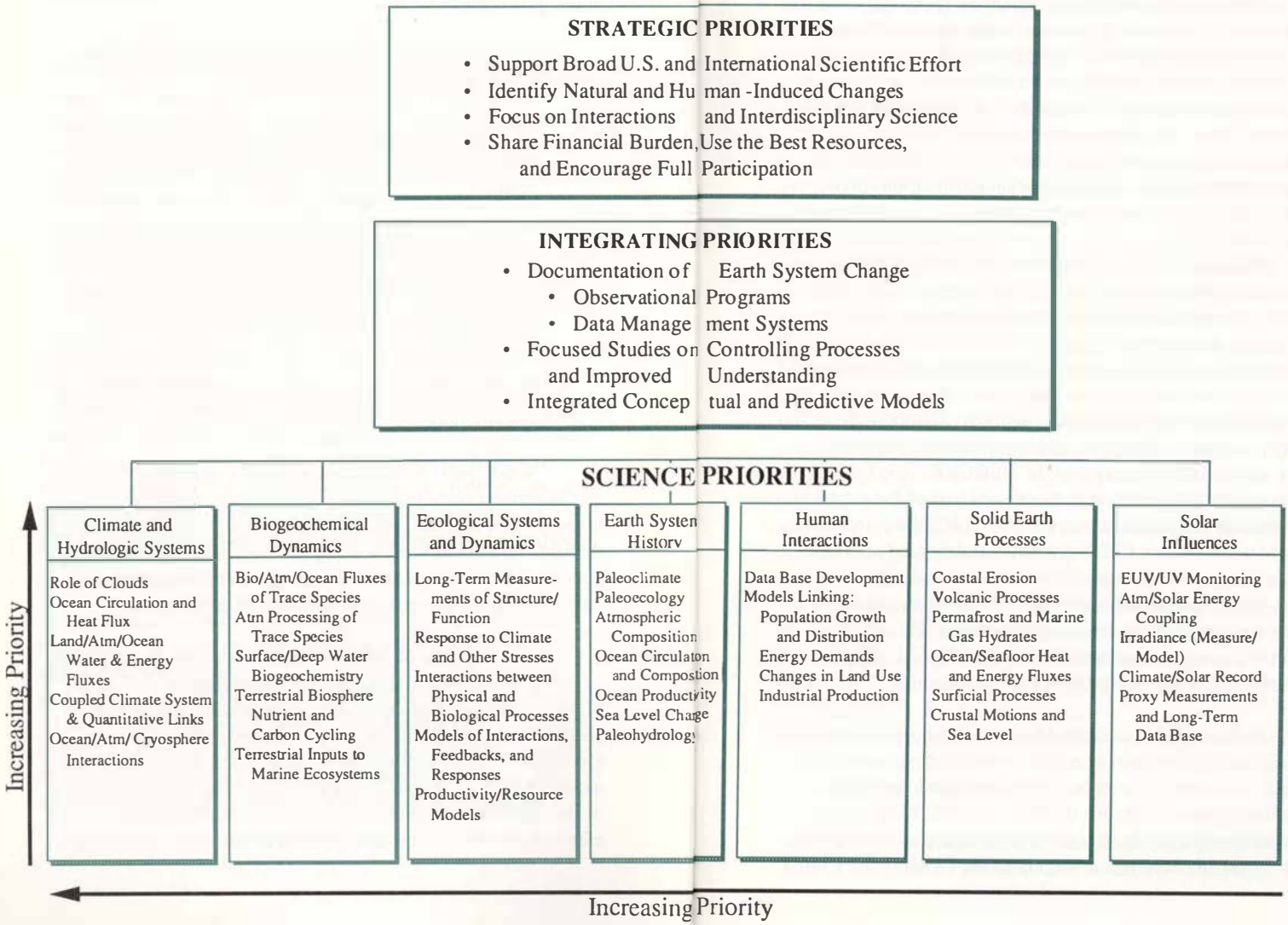
- To develop integrated conceptual and predictive Earth system models.

Work towards these objectives proceeds simultaneously and in concert since progress in each influences the others. It is recognized that the goal and objectives can best be achieved through the mutually-reinforcing research activities of all nations and many organizations and programs which require a large measure of bilateral and multilateral cooperation.

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

Figure 1

U.S. Global Change Research Program Priority Framework



management systems, to facilitate the organization and 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. plans a comprehensive series of satellite launches through the coming decade to provide these global long term observations, with a full scale Earth Observing System (EOS) in full operation by 1988.

Within the priority framework, the CEES evaluates the proposed projects on the basis of (i) their relevance and contribution to the overall USGCRP goal and objectives; (ii) scientific merit as documented by peer review; (iii) readiness for implementation and likelihood of early results; (iv) linkages to other national and international programs; (v) costs in the short- and long-term; (vi) enhancements to existing high priority programs before starting new initiatives; and (vii) agency approval for inclusion in the USGCRP. The framework and the evaluation criteria are an essential part of the program and budget development strategy of the CEES and 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. This enables CEES to develop and recommend an evolving USGCRP which supports U.S. global change policy interests.

The USGCRP 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). 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).

The FY 1992 Program

The USGCRP was developed in response to the evolving nature of Earth science research to a more multidisciplinary or "Earth System Science" approach. The foundation of Earth System Science is the belief that sound scientific information on global change must be derived from a comprehensive, integrated view of the interactions among key components of the Earth system, and the influence of human activities on them. Overall constraints on Federal funding have led the CEES to pursue a program more focused on the highest priority scientific and policy issues over the next few years. Even with this increased focus, the budget requests a 24.2 percent increase, a rate of growth far surpassing most other government programs. In particular, the highest priority scientific and policy-related issue for the USGCRP in FY 1992 is whether, and to what extent, human activities are changing or will change the global climate system.

In this context, the CEES relied on the results of the Scientific and Impacts Assessments of the Intergovernmental Panel on Climate Change (IPCC) in developing the FY 1992 Program. Specifically, the FY 1992 USGCRP will:

(1) Enhance research that seeks to reduce the scientific uncertainties identified during the IPCC scientific and impacts assessments, especially:

- sources and sinks of greenhouse gases, 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 availability;
- polar ice sheets, which affect predictions of global sea level changes; and
- ecological dynamics, which are impacted by and respond to climate change; and

(2) Enhance scientific research to address greenhouse gases comprehensively, rather than on a gas-by-gas basis. Priorities include:

- sources and sinks of greenhouse gases;
- development of a quantitative index of radiative forcing; and
- development and use of economic models to generate predictions and scenarios that cover multiple greenhouse gases and multiple economic sectors.

Planning for the FY 1992 USGCRP, as in previous years, has been guided by the extensively reviewed strategic, integrating, and scientific priorities of the planning framework (Figure 1) and the evaluation criteria. The results of the IPCC scientific and impacts assessments were utilized in developing the USGCRP to ensure that the Program is responsive to the highest priority global change policy issues. The proposed FY

1992 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 databases 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. Using the information needs identified by the IPCC as a guide, four high priority Integrating Themes were adopted in FY 1992. Addressing these themes requires efforts in most of the seven science elements (including Human Interactions) and, therefore, provides an enhanced level of integration for the Program. These FY 1992 Integrating Themes allow the CEES agencies to focus the collective efforts of government and academic scientists, in collaboration with scientists from other countries, on a number of high priority, multi disciplinary investigations which respond to some of the current critical information needs in global change. The four FY 1992 Integrating Themes are:

(1) C*limate 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.

(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:

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

- role of the oceans: the exchange of energy and mass (e.g., water) between the ocean, sea ice, and the atmosphere; between the upper layers of the ocean and the deep ocean; and transport within the ocean;

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

- change in sea level, which is 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.

(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; the chemical, biological and physical processes that control their fluxes; how these fluxes may be influenced by climate change; and how changes in greenhouse gas abundances affect the magnitude and rate of change.

(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:

- species composition of ecosystems;
- distribution and extent of ecosystems; and
- productivity of ecosystems.

The four Integrating Themes for FY 1992, 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 1992, the President's Budget request also includes enhanced resources to support economics research related to global change, and resources to maintain programmatic momentum in a number of other critical USGCRP investigations. These include continued support for investigations in the areas of stratospheric ozone, human interactions, solid earth processes, and solar influences. Detailed information regarding FY 1992 USGCRP plans in these areas follow the discussion of the Budget by Integrating Theme.

For FY 1992, 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: the Tropical Ocean and Global Atmosphere (TOGA) Program, the World Ocean Circulation Experiment (WOCE), the Joint Global Ocean Flux Studies (JGOFS) Program, the International Global Atmospheric Chemistry (IGAC) Program, the Global Energy and Water Cycle Experiment (GEWEX), Biospheric Aspects of the Hydrologic Cycle (BAHC), Global Change and Terrestrial Ecosystems (GCTE), and Past Global Changes (PAGES). These activities direct

resources to that portion of Earth system science where scientific advancement can contribute to decreases in uncertainty in the near term. This approach also fosters the international cooperation essential to rapid achievement of scientific understanding. However, pursuing a Program focused on these IPCC scientific and impacts issues in the near-term will require continued interaction with the national and international scientific communities in discussions of scientific priorities.

Policy Relevance of Integrating Themes

The global changes of primary concern to national and international policymakers are those that could impact the Earth's life-support system. Prudent environmental policy formulation will require a defensible scientific understanding of how the Earth system, hydrologic cycle, carbon cycle, and biological resources vary naturally, how human activities change them, and how they might respond to future changes in environmental conditions. Central to this concern are questions about the Earth's future climate, such as the global and regional distributions of temperature, precipitation and storm frequency and intensity, including the question of climate change due to greenhouse warming. Of equal concern are questions about changes in the Earth system that may result from future climates, such as sea level, biological productivity and diversity, and the chemical composition and water storage capacity of soils. The task of predicting the biological impacts of both climate and other environmental changes is made more difficult by the complexity of interactions and feedbacks among these components.

Climate Modeling and Prediction

One of the principal objectives of the USGCRP is to support national and international policymaking by developing the ability to predict the nature and consequences of changes in the Earth system, particularly climate change. Understanding and predicting changes in the Earth system requires that many

distinct research components be successfully linked. The atmosphere, the ocean, the cryosphere, the land surface, and terrestrial and marine ecosystems all operate together as a complex interrelated system. The Earth system is too complex to allow direct experiments that would yield reliable predictions of future environmental changes. Therefore, simplified predictive models are used to simulate the physical, geological, chemical and biological processes governing the behavior of the Earth system. Because of an insufficient understanding of key Earth system processes, and the inadequate capacity and speed of computers required to simulate the coupled ocean/atmosphere/land Earth system as a single entity, models that predict separately the components of future environments are currently used. The central task of the USGCRP is to understand the processes and integrate the predictions from these various models to provide leaders of governments with the best possible scientific information as input to environmental policy decisions.

Global Water and Energy Cycles, including Sea Level Change

The global hydrologic cycle plays a pivotal role in the Earth's radiation and heat budgets. The distribution of clouds and water vapor, for example, play a key role in controlling the amount of solar energy absorbed by the Earth system as well as the infrared radiation emitted to space, and they strongly influence the redistribution of heat throughout the Earth system. The future availability of adequate water supplies is the most significant natural resource issue in many regions throughout the world. Any substantial rise in sea level would have a major economic impact on low-lying coastal areas, resulting in erosion, inundation, and/or wetland loss. The USGCRP is pursuing a broadly-based suite of projects addressing important aspects of the global water and energy cycle problem. These projects include the study of atmospheric water vapor (the most radiatively active gas in the atmosphere), clouds and their role in climate system feedbacks, precipitation and its distribution over land and sea, changes in the volume

and areal extent of sea ice and polar ice sheets, the role of the oceanic circulation in absorbing gases and redistributing heat, and the interaction of terrestrial ecosystems with the atmosphere.

Global Carbon Cycle

Human activities are resulting in significant alterations in the biogeochemical cycling and partitioning of carbon throughout the Earth's environment. There is now unambiguous scientific evidence that the atmospheric concentrations of several key radiatively and chemically active gases, such as carbon dioxide and methane, are increasing primarily due to human activities, thereby increasing the total radiative forcing of the atmosphere. Other gases, such as carbon monoxide and possibly non-methane hydrocarbons, the oxides of nitrogen (NO_x), and ozone are also increasing, and these gases have important roles in photochemistry and the lifetimes of methane and other radiatively active gases. There are significant uncertainties in understanding the key processes in the carbon cycle that control the sources and sinks of these gases, which limit the ability to predict their future concentrations. An improved understanding of the carbon cycle would help to overcome uncertainties that impact the ability to assess radiatively active gases from a comprehensive perspective. Hence, focused research requires improved knowledge of atmospheric lifetimes, global warming potentials, chemical, biological and physical processes that control terrestrial and oceanic sources and sinks, and methods of monitoring emissions. This type of information is essential to develop, implement and determine the effectiveness of national and international response strategies for controlling anthropogenic greenhouse gas emissions or altering the natural carbon cycle through reforestation or enhanced carbon fixation in oceanic ecosystems.

Ecological Systems and Population Dynamics

The consequences of changes in radiative forcing and climate on biological resources and their dynamics are of critical importance. Human factors (e.g., economics, legal and regulatory systems) influence how these resources are developed and managed throughout the world (see discussion of economics research in the Special Issues section). Humans also cause large scale environmental changes in very direct ways, such as through deforestation, urban expansion and agricultural practices that degrade soils. The study of population dynamics provides links among these interacting social, economic, biological and ecological systems. Some of these links are explicit, e.g., managing food resources; others are inadvertent, e.g., the consequences of urban expansion on wetlands and wildlife habitat or over fishing of fish stocks. However, the ecological, biological, and economic processes that control these impacts are not well understood, and predictions of impacts suffer from great uncertainty. The USGCRP projects encompass both causes and effects of global change, from considering how changes in human populations and consumption patterns affect greenhouse gas emissions, to how rapid changes in climate and atmospheric carbon dioxide may alter the productivity and distributions of naturally regulated plant populations. Studies of population dynamics span spatial scales — from small-scale experiments on how competing plants may grow in high carbon dioxide atmospheres, to larger-scale considerations of how global food availability may be affected under global change. National and international decisionmakers, agriculturalists, land managers and the general public must know how global change will affect biological resources, and what can be done to plan for it.

Research Program and Budget

This section will highlight the FY 1992 USGCRP and budget by Integrating Theme, by science element, by scientific objective, by agency and by federal budget function. The President's FY 1992 budget proposes a funding level of $1186 million, a $232 million (24.2 percent) increase over the FY 1991 enacted level.

Budget by Integrating Theme

This section summarizes the FY 1992 activities in the four Integrating Themes. 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 briefly described in either the "other research activities" or special issues sections. Table 1 and Figure 2 show the USGCRP budget by integrating theme.

Figure 2
U.S. Global Change Research Program Budget by Integrating Themes

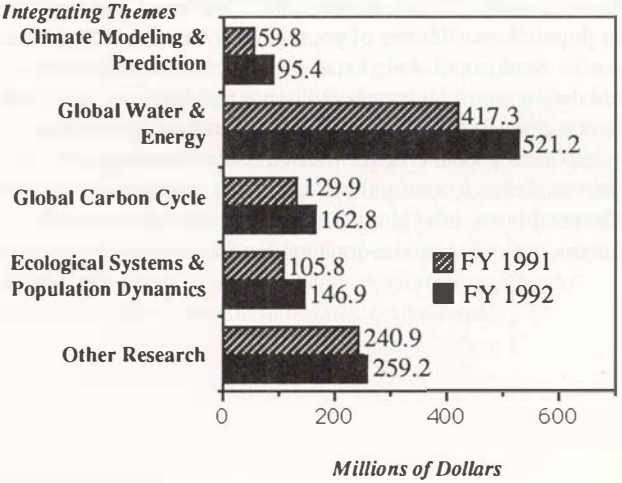


Table 1
FY 1991-1992 U.S. Global Change Research Program Focused Budget By Integrating Theme
(Dollars in Millions)

Focused Program	Total Budget		Climate Modeling and Prediction		Global Water and Energy Cycles (inc. Sea Level Change)		Global Carbon Cycle		cological Systems and Population Dynamics		Other Research Activities	
	1991	1992	1991	1992	1991	1992	1991	1992	1991	1992	1991	1992
Agency Totals	953.7	1185.5	59.8	95.4	417.3	521.2	129.9	162.8	105.8	146.9	240.9	259.2
DOC/NOAA	47.0	78.0	11.3	20.2	28.1	44.1	5.4	7.2	0.6	2.4	1.6	4.1
DOD	0	6.3	0	0	0	4.8	0	0.3	0	1.0	0	0.2
DOE	65.6	77.0	21.9	26.5	27.2	32.0	16.5	18.5	0	0	0	0
DOI	36.6	46.4	4.3	4.9	18.1	20.7	4.8	5.0	8.1	14.0	1.3	1.8
EPA	21.8	26.0	0	0	0	0	12.2	14.8	6.3	7.4	3.3	3.8
NASA	651.6	772.6	14.9	27.9	312.5	377.7	57.6	70.5	51.2	72.1	215.4	224.4
NSF	87.1	118.5	5.1	10.4	29.0	39.0	21.3	30.1	13.1	19.4	18.6	19.6
SMITHSONIAN	5.4	7.5	0	0	0.1	0.1	1.1	1.9	3.5	4.5	0.7	1.0
USDA	38.6	53.2	2.3	5.5	2.3	2.8	11.0	14.5	23.0	26.1	0	4.3

Climate Modeling and Prediction

The FY 1992 request for this integrating theme is $95.4 million, a $35.6 million or 59.5 percent increase over the FY 1991 enacted level.

Scientific Understanding

Prediction of climate and environmental changes is not straightforward given the complexity of the Earth system and its many feedbacks. For example, the human-generated increases in atmospheric carbon dioxide concentration are a major factor potentially causing climate change. However, because carbon dioxide is the primary raw material for photosynthesis, increased carbon dioxide concentrations are also likely to have a direct biological effect manifested as changes in the extent and distribution of the Earth's vegetative cover. This, in turn, affects hydrology and surface albedo and could affect climate. Such complex Earth system processes and interactive feedbacks can only be understood through model simulations.

Today's global models simulate with acceptable confidence some of the important processes of global change, such as the direct response of the climate system to increased atmospheric concentrations of greenhouse gases (i.e., tropospheric warming and stratospheric cooling). Many physical processes, however, are treated only in a rudimentary fashion by the models (cloud-radiation interactions, ocean circulation, changes in the distribution and abundance of biota, biologically modulated elemental cycling, and ocean and terrestrial exchanges with the atmosphere of heat, water, carbon dioxide and other gases).

Today, scientists model individual components or limited subsystems of climate, such as the atmosphere; the atmosphere and ocean; or the atmosphere, ocean and prescribed land-surface, rather than the entire coupled system.

More reliable climate change predictions, especially at the regional scale, will require representation of the integrated behavior of the climate system with fully coupled subsystem models.

The primary climate models, called general circulation models (GCMs), predict a variety of climatic variables, such as temperature, precipitation, winds, snow accumulation, and soil moisture. Of the possible global climate models in use, only the GCMs provide geographical distributions of these variables and hence, regional predictions. To be used for global change predictions, atmospheric GCMs must be integrated with models of the ocean and land surface and the biotic changes inherent to them.

Research Needs

Observations of a wide variety of past and present physical, geological, chemical, and biological parameters associated with the atmosphere, land, and ocean will be required to improve scientific understanding of how the Earth functions as a single coupled system. Good data and information management are essential to accomplish this. Data sets must be organized and assimilated so the model simulations of present and past environments can be compared to nature as a test of model accuracy.

Model development requires greater understanding of processes within each component of the Earth system (e.g., cloud-radiation interactions) and of processes that involve interactions between two or more of the components (e.g., the roles of the oceans and terrestrial biota as sinks for atmospheric carbon dioxide) and changes that may occur in these processes under different climatic regimes. These processes cut across virtually every scientific element within the USGCRP.

Improving the certainty of climate change predictions at both global and regional scales arising from either natural

variations in the Earth's climate system or in response to assumed anthropogenic greenhouse gas emissions scenarios will require significant new computational capabilities. Estimated needs require a thousand-fold increase in computer time. The USGCRP will seek new technology and techniques to enhance computational capability for the USGCRP, both through the Program and through linkages to other programs and initiatives, such as the President's new initiative in High Performance Computing and Communications Program.

FY 1992 Research

To achieve the USGCRP's objective of developing a predictive capability for the Earth as an coupled system, the Program's activities of observations, data management, and understanding must all contribute to model development, documentation, testing, application and verification. The proposed USGCRP is structured to accomplish this. In FY 1992, the Program requests $95.4 million to support predictive climate modeling activities across all of the science elements. Highest priority will be associated with the Climate and Hydrologic Systems, Biogeochemical Dynamics, Ecological Systems and Dynamics, and Earth System History science elements.

A strong and focused multi-agency program includes the development, application, and validation of global predictive models of climate change. It is a complementary and coordinated (DOE, NASA, NOAA, NSF, DOI, and USDA) research effort, which:

- highlights research on data assimilation and production of GCM-assimilated climate data sets for model development and evaluation, and for preparing for future Earth Observing System (EOS) data streams.

- centers on improved process representation (parameterizations) and regional resolution and

the separation of natural climate changes from those associated with human activities.

- focuses on the development of advanced computational methodologies and capabilities for integrated climate models of the future.

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

- focuses on reconstructing and simulating past global change by producing and integrating paleoclimate time series from many sources into a single, usable global database accessible to modelers.

Global Water and Energy Cycles, including Sea Level Change

The FY 1992 request for this integrating theme is $521.2 million, a $103.9 million or 24.9 percent increase over the FY 1991 enacted level.

Scientific Understanding

The energetics of the atmosphere are strongly influenced by the presence of all three phases of water in the atmosphere. Of significance are interactions between radiation and water vapor (the most important greenhouse gas), the transport and convergence of water vapor in the atmosphere, and the formation of clouds. Clouds play a special role because they are critically important in both energy and moisture exchange. Scientific understanding of these processes is held back by inadequate knowledge of how water in the atmosphere, forced to condense, is organized into clouds of varying type and spatial distribution.

The oceans are by far the dominant reservoir on the planet for both water and heat. Evaporation and precipitation over the oceans result in the exchange of latent heat, as well as water, with the atmosphere. In turn, precipitation and evaporation exert a strong control on salinity, water mass formation, and the deep circulation of the oceans. A prominent example of the interaction of the upper ocean and the atmosphere is provided by the El Niño/Southern Oscillation (ENSO). Major shifts in upper ocean and atmospheric circulation in the tropical Pacific result in global changes in the distribution of precipitation on interannual time scales. On time scales of decades to centuries, considerably longer than ENSO, paleoclimate studies and coupled ocean-atmosphere models suggest large-scale alterations in the north-south distribution of precipitation associated with variation in the deep circulation of the oceans.

Recent research has also shown the importance of land surface processes as modulators of the supply of heat and moisture available in air masses as they move across continents. Although the basic processes that govern the movement of water, from precipitation, infiltration though the soil, groundwater recharge and river runoff are reasonably well understood over small areas, they are poorly understood over larger regions and continental-sized areas. It is well known that soil moisture provides a source of atmospheric water vapor that can then produce precipitation. Thus a large area of wet soils can enhance precipitation, while a drought (and the associated dry soils) can become self sustaining. Therefore, terrestrial ecosystems play an important part in these land surface processes.

In response to global climate change, the IPCC Science Panel/WGI has said that future absolute sea level is expected to rise as glaciers melt and seawater expands in volume. During the past century (in response to a global climate warming interval), it is estimated that absolute sea level has risen about

20 cm from the observed worldwide retreat and melting associated with the shrinking of temperate glaciers, especially those in southeastern Alaska, and from thermal expansion of the oceans. Because of the problems associated with analyses of tide-gauge data (poor geographic distribution of tide gauge sites, inadequate length of records, unstable geologic settings, etc.), it is difficult to extract meaningful information from them. Sea level measured by a tide gauge which is not tied to an external geodetic reference system will only provide measurements of relative sea level, from which it may be difficult or impossible to determine absolute sea level. Coastal regions may be undergoing tectonic uplift or downfaulting, undergoing compaction of deltaic sediments, or still being subjected to crustal rebound following unloading of an ice sheet.

There are enormous uncertainties associated with the sea level question because of the complex interrelationships between: carbon dioxide concentration and temperature of the Earth's atmosphere; cyclical, long-term variations in seasonal hemispheric insolation and global climate; glacier mass balance and climate; rate and magnitude of the exchange between glacier ice and ocean reservoirs; rate and magnitude of thermal expansion of the oceans; and the difficulty of accurately measuring absolute changes in sea level from tide gauges.

Research Needs

Atmosphere: The capability of minor adjustments in relative humidity distribution to alter the characteristics of clouds and hence alter the radiation balance of the atmosphere remains a critical issue. The nature of the feedback between global warming, clouds and water vapor as a radiatively active gas must be better understood and quantified than at present. The connections between the large-scale climate system and a potential redistribution of worldwide cloud and rainfall patterns represent a serious deficiency in the ability to model and predict Earth system behavior.

Ocean: The ocean serves as a major thermal conduit between the tropics and polar regions of the Earth. Many oceanic processes critical to problems of long-term change are affected fundamentally by exchange of energy and latent heat (water) across the air/sea interface. Much of the deep circulation of the ocean is strongly determined by patterns of precipitation, evaporation and surface runoff, and the transport of sea ice by surface winds. The cycling of energy and water in the Earth system as a "complete" problem requires a thorough understanding of these related oceanic processes.

Land Surface: The hydrology of the land surface is an exceedingly complex system to understand and model. The conservation of water and energy associated with the interactions of atmospheric phenomena such as precipitation and wind with terrestrial hydrology through fluxes of heat and moisture, represents critical constraints in understanding and modeling Earth system behavior. Realistic models of the land surface component of the climate system are dependent upon the development of improved characterizations of local-scale processes and interactions at regional and broader scales. In particular, there is a significant need for improved understanding of (1) evapotranspiration from diverse vegetation, lakes, and other land cover types; (2) infiltration of water through the unsaturated zone and aquifer recharge; (3) the conversion of precipitation to stream flow, including the role of topography at a variety of storm and catchment scales; (4) the processes of snow accumulation, transformation, redistribution, melting, and the growth or shrinkage of glaciers at high latitudes or elevations; and (5) the extent and dynamics of permafrost in polar regions.

Sea Level: There needs to be a better understanding of the relationship between carbon dioxide concentrations in the Earth's atmosphere, temperature and global ice volume. Long-term cyclical or secular variations in solar energy reaching the Earth's surface on a seasonal basis and at different latitudes must also be better understood. A better understanding of the

relationship of regional and global climates and glacier mass balance is required, especially the present-day mass balance of the different components of the Greenland and antarctic ice sheets. The rate and magnitude of exchange of water between glacier ice and the oceans during the past 200,000 years is needed. An improved understanding of the rate and magnitude of thermal expansion of the oceans is needed for different warming scenarios. The most important issues regarding sea level are: to determine the contemporary rate of change in global absolute sea level, detect any change in that rate with time, identify the ice mass changes associated with observed changes in sea level, and estimate the expected change in sea level during the next decade to century.

Modeling: Representation of the hydrologic cycle is one of the major acknowledged weaknesses in climate general circulation models. For example, in several coupled climate models, errors in the flux of water between ocean and atmosphere result in anomalous distributions of sea surface salinity and ultimately, unrealistic model results. While flux correction routines are used to counteract the growth of such errors, better model representation of the movement of water on the planet is the ultimate answer. On smaller space and time scales, projections of regional drought using numerical models appear within reach using extensions of existing weather prediction approaches. Scaling issues also dominate the challenge of modeling the terrestrial biological component of the hydrologic cycle.

FY 1992 Research

Ongoing research programs, augmentations and new initiatives of the USGCRP will each contribute to different aspects of the required research. The agency programs are listed in a table in the Appendix, along with their FY 1991 enacted and FY 1992 requested budgets. FY 1992 programs will specifically include:

Atmosphere: Substantial ongoing and new research programs are focused on this area. Ongoing activities include the NASA, NOAA, NSF International Satellite Cloud Climatology Project (ISCCP); 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, and DOI), which will address the processes controlling the distribution of water and energy on the planet; DOE's Atmospheric Radiation Measurement (ARM) program, which will focus on extensive ground-based measurements of clouds and radiation; and NASA's EOS mission, which will provide the larger-scale perspective from space. DOE's Quantitative Links program examines the relationships between atmospheric composition and global climate change, is another continuing program. New activities this year include NSF's Role of Clouds program, targeted specifically towards quantifying the radiative effects of clouds on a global scale. The Greenland Ice Sheet Program (GISP), a component of NSF's Arctic System Science (ARCSS) initiative, will produce new data concerning paleoclimate. Funding is also requested for NASA's Tropical Rainfall Measurement Mission (TRMM), a critical expansion of efforts to quantify precipitation in lower latitudes.

Ocean: The overall USGCRP effort in this area consists of a broad examination of the general circulation of the ocean and basin-scale studies of particular modes of ocean-atmosphere interaction, together with the building of an upper ocean observing system to quantify air-sea fluxes on a continuing basis. The World Ocean Circulation Experiment (WOCE: NSF, NOAA, NASA, DOD and DOE) is a measurement and modeling program of the circulation of the global ocean. The Tropical Ocean-Global Atmosphere Program (TOGA: NOAA, NSF, and NASA) has provided major advances in the understanding of interannual climate change, particularly its interactions with the tropical Pacific. Another basin-scale study, the

NOAA Atlantic Climate Change Program aims at examining the interactions between the Atlantic and global climate. *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, while the new generation of space-based measurements of ocean altimetry, temperature, and wind stress (NASA EOS, NASA Scatterometer/ADEOS, TOPEX/Poseidon) 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), since wind stress measurements over the oceans will be critical to estimating the air-sea fluxes of heat and momentum. Several agencies (NSF, NOAA, DOI, SI, and DOD) will conduct paleooceano-graphic studies to provide improved documentation and understanding of past changes in deepwater formation and circulation, including possible abrupt mode shifts such as the Younger Dryas cold period which involved an abrupt reversal of a general global warming trend in progress around 10,500 B.P. and lasted about 500 years; and past changes in sea-surface temperatures as well as changes in patterns and intensity of surface currents.

Land Surface: A central problem in land surface hydrology involves relating local scale hydrologic processes to those at regional, continental and global scales. Coupling spatially detailed hydrologic models with spatially coarse general circulation models requires the development of a new class of models that can bridge the gap between the catchment and GCM grid scales, as well as improved understanding of hydrologic processes in large basins. A number of agencies are proposing modeling activities and basin studies to address this requirement, including DOI (Interaction of Climate and Hydrologic Systems, Regional Studies, Sensitivity of Hydrologic Systems, Sensitivity of Water Resources), DOD (Coupled Hydrologic/Thermal Basin Modeling), and USDA (Scale Effects of Hydrologic Processes). 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 the NSF Continental Hydrologic Processes program. NSF will also support the planning and development of the Water-Energy-Vegetation (WEV) project, which focuses on interactions between vegetation and the physical environment, specifically water and energy. Integration for many of these projects will be provided by the Global Energy and Water Cycle Experiment (GEWEX) program, which will initiate a continental scale study in North America. Lastly, the global observational context for these land surface studies will be provided by the EOS platform. In addition, there will be a significant expansion of research in polar regions in FY 1992. The NSF Arctic System Science program will initiate coordinated interdisciplinary investigations of Arctic ocean-ice-atmosphere interactions, while the DOI Cold Regions Research program will be directed toward understanding changes in glaciers, permafrost, snow cover, and floating ice. Paleoecological studies in NSF, DOI, USDA, and SI will provide information on changes in vegetation associated with past climate changes.

Sea Level: After evaluating national and international policy needs, scientific background, and required understanding, a responsive multi-disciplinary research effort was developed. Increased effort in ongoing projects and several new projects are focused on sea level during FY 1992. These include the following programs: increased deployment for 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 (DOE, NASA, NSF, and NOAA); and crustal motions and sea level (NASA, NOAA, and NSF). Considerable research will contribute to understanding past variations in sea level, including: the second Greenland Ice Sheet Project (GISP II) which will recover data in ice cores from Greenland (150,000-year record) (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 of NSF; and the reconstruction of sea level history and its relationship to climate change (DOI). The impacts of sea level change will be addressed under two programs: Models of Human Interactions in Global Change (NSF); and Coastal Erosion, Inundation, and Wetlands Loss (DOI).

Modeling: As described in the Modeling and Prediction Integrating Theme, a complementary interagency (DOE, NASA, NOAA, NSF, and DOI) program for the development and application of predictive models of climate change is proposed for FY 1992, with a strong emphasis on hydrologic cycle issues. It emphasizes the integration of subsystem models (atmospheric, oceanic and land surface) to build the coupled climate models necessary for more certain predictions of climate change; it highlights the development of advanced computational methodologies and capabilities for integrated climate models of the future; it focuses on improved process representation and regional resolution and the separation of natural climate changes from those associated with human activities; and it includes research and production of GCM-assimilated climate data sets for model development and evaluation, and for preparing for future EOS data streams.

Global Carbon Cycle

The FY 1992 request for this integrating theme is $162.8 million, a $32.9 million or 25.3 percent increase over the FY 1991 enacted level.

Scientific Understanding

The IPCC highlighted the need for an improved understanding of the sources and sinks of radiatively and chemically active atmospheric gases, their chemical reactions in the atmosphere, and how they may be influenced by climate change.

Carbon Dioxide: The concentration of atmospheric carbon dioxide is now about 350 parts per million (ppm) (1989), and is increasing at a rate of about 1.8 ppm per year. The challenge in carbon cycle research is to understand the fate of the "new" anthropogenic carbon (about 6-8 billion metric tons of carbon as carbon dioxide) released annually from human activities. Although very small in comparison to the natural fluxes, human-influenced fluxes have been large enough to increase atmospheric carbon dioxide concentrations by 25% since pre-industrial times. Indirect evidence suggests that the land and oceans may sequester anthropogenic carbon dioxide in roughly equal proportions (about 2 billion metric tons each per year), although the mechanisms are not well understood. Recent models suggest that the most significant land or ocean sinks may be in the Northern Hemisphere.

The rate of carbon dioxide uptake by the oceans is controlled by both the exchange rate at the sea-air interface and the chemical, biological, and physical processes that transfer carbon-containing surface water to the deep ocean and sediments, where it is sequestered for long periods. There are suggestions that human influenced sources of nutrients may be increasing productivity in near-shore and/or oceanic ecosystems. Several possible mechanisms have been suggested for enhanced sequestration of carbon by terrestrial ecosystems: (1) enhanced productivity under warmer conditions, (2) direct effect of enhanced photosynthesis due to increased atmospheric carbon dioxide and enhanced deposition of nitrogen compounds, and (3) land management practices that may have sequestered additional carbon in terrestrial ecosystems.

Methane: The current atmospheric methane concentration is 1.72 ppm, more than double the pre-industrial value, is increasing at a rate of 0.9% per year, and is greater today than at any time during the last 160,000 years. Methane is produced from a wide variety of anaerobic sources. Important sources of methane include natural wetlands (tropical and high latitude peatlands), rice cultivation, enteric fermentation in animals,

biomass burning, methane clathrates, and natural gas venting. Less well known are the environmental, physical, geological, chemical and biological processes that control the releases of methane to the atmosphere. Hence, a key requirement in understanding atmospheric methane is to quantify the fluxes of methane from different sources, and to identify and understand the processes that control these fluxes and their sensitivities to climate change.

Oxidation in the troposphere is the major sink for atmospheric methane, and results in an atmospheric lifetime of about 12 years. Photochemical models currently suggest that the atmospheric oxidizing capacity may be declining, which would imply a longer residence time for methane. However, while the knowledge of the sources and sinks of atmospheric oxidants has improved over the past decade, it is still incomplete. The natural sources of tropospheric oxidants are downwelling of ozone from the stratosphere and photochemical reactions involving nitrogen oxides, carbon monoxide, methane, and non-methane hydrocarbons, which have both natural and man-made sources. There is now evidence to suggest that, during the past century, oxidant (primarily ozone) levels in industrialized and remote areas in the Northern Hemisphere areas have increased due to growing abundances of the above pollutant precursors.

Research Needs

Understanding the carbon cycle requires scientific information spanning numerous scientific disciplines and all seven scientific elements and three scientific objectives of the USGCRP. The scientific needs can best be described within the following framework:

Atmospheric Carbon: Reconstruct historic and monitor contemporary atmospheric distributions and trends of carbon dioxide and methane, including their isotopic composition.

Identify and understand the atmospheric processes responsible for removal of methane isotopes in an effort to more accurately quantify sources. Additionally, it is important to investigate, through laboratory and field studies, the atmospheric and physical-chemical processes involving ozone, carbon monoxide, nitrogen oxides, and non-methane hydrocarbons that affect atmospheric lifetimes and that control the escape of chemically active compounds from the surface to the global atmosphere.

Oceanic Carbon: Quantify the local, regional, and global fluxes of carbon dioxide (including isotopic composition) between the atmosphere and oceans and understand the ecological, biogeochemical, and physical processes (a) that control the fluxes of carbon dioxide between the atmosphere and ocean surfaces, (b) that are responsible for the exchange of carbon between the land, ocean margins, surface waters, deep ocean waters, and sediments, (c) that control the cycling and transformation of carbon within the oceans (between dissolved and particulate inorganic and organic carbon compounds); and (d) that may respond to changing environmental conditions (e.g., ocean temperature, ocean circulation, air-sea exchange rates, etc.).

Terrestrial Carbon: Quantify the local, regional, and global fluxes of carbon dioxide, methane, carbon monoxide, and non-methane hydrocarbons (including their isotopic composition) between the atmosphere and a wide range of natural and managed terrestrial ecosystems and understand the ecological, biogeochemical and physical processes that control the (a) fluxes and isotopic composition of these carbon gases between the atmosphere and the terrestrial biosphere and (b) amount of carbon stored in different terrestrial ecosystems and their structural components (e.g., live biomass, detritus, soil, permafrost, and sediments), and (d) cycling and transformation of carbon within the terrestrial biosphere. It is particularly important to understand the impact of changing climate conditions, the effect of increased carbon dioxide, the frequency of

fires, and chemical deposition on growth and carbon fixation by vegetation.

Human Dimensions of the Carbon Cycle: Identify patterns of change in anthropogenic sources and sinks at local, regional, and global scale. This will involve determining the influence of 1) economic and population forces in these changes, 2) the relationships among fluxes in carbon dioxide and methane and changing patterns of land use and food production, marketing, and consumption; 3) the relationship among economics, industry, transportation, and local, regional, and global fluxes of carbon dioxide, methane, carbon monoxide, and non-methane hydrocarbons, e.g., carbon dioxide from the combustion of fossil fuels (see Economics Research under Special Issues section).

Global Carbon Models: Develop global carbon models to synthesize the understanding of the processes that control the distribution and partitioning of carbon within the atmosphere, oceans, and terrestrial ecosystems, and the fluxes among them. Such models should ultimately comprise an atmospheric model of carbon dioxide circulation and photochemical carbon processes, an oceanic circulation model incorporating chemical, biological and physical processes, and terrestrial models of carbon cycling in ecosystems and carbon dioxide exchange with the atmosphere. Tested models will simulate the atmosphere-ocean-terrestrial exchange processes, and will be used to predict future concentration of carbon dioxide and methane in relation to altered human and natural sources and sinks.

FY 1992 Research

Ongoing research programs, augmentations and new initiatives of the USGCRP each contribute to different aspects of the required research. The agency programs are listed in the Appendix, along with their FY 1991 enacted and FY 1992

requested budgets. FY 1992 programs will specifically 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 NASA's Global Tropospheric Experiment (GTE) in the tropics (Brazil), northern wetlands (Canada), and the eastern Pacific. The focus 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-area site. Such studies will also include the International Global Atmospheric Chemistry (IGAC) projects in the northern Atlantic, which is a region perturbed by human-made emissions (NOAA and NSF).

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, whose goals 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.

NOAA, DOI, and DOD will perform contemporary and paleooceanographic studies utilizing geochemical, isotopic,

and paleontologic data to provide an improved understanding of past changes in: (i) deep water formation and circulation, including areas of formation, rates and patterns of flow, and possible abrupt mode shifts such as occurred during the Younger Dryas period; (ii) productivity of surface waters and carbon sequestration in lake, coastal and oceanic sediments; and (iii) sea surface temperature and surface currents.

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 Earth Probes is expected about 1994-95, and the EOS missions 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, land-fills, 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 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, NOAA, DOE, and NASA will utilize existing satellite imagery (Landsat, Advanced Very High Resolution Radiometer - AVHRR, and other) for land-cover classification, 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 (see discussion of economics in the Special Issues section). 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.

Ecological Systems and Population Dynamics

The FY 1992 request for this integrating theme is $146.9 million, a $41.1 million or 38.8 percent increase over the FY 1991 enacted level.

Scientific Understanding

Current scientific knowledge positions the USGCRP well to undertake major research efforts in population dynamics. In both methodological and substantive areas, the USGCRP will be building on a secure and well-founded base of knowledge in five major areas.

Sampling, Monitoring, and Database Development: In situ methods for sampling human and terrestrial biological populations are more advanced than for aquatic populations. Crop yields, fishery and forestry resources, and the abundances of game and some non-game species are measured routinely by Federal, local and state governments in many nations and by international organizations. Indices of distribution of major plant life-forms (but not individual species) and ocean color can be made from space, (e.g., from AVHRR and Coastal Zone Color Scanner (CZCS) data). Sampling statistics are extremely well developed in both the social and natural sciences, and surveys are routinely conducted on samples of human populations. Databases are less well developed.

Dynamics of Growth and Decline: The sensitivities of populations to global change depend on several factors, including the health of the individuals, their absolute numbers, their location relative to their natural environmental range, the existence of competitors and/or predators and pests, and the existence of keystone species. Adaptation to natural disturbances (i.e., hurricanes and fire) also influence species distributions and abundances. The nature and rate of growth in human populations are well understood. The influence of society,

economics, and legal inputs and practices on human populations is less well understood, but has been the topic of extensive theoretical and empirical research. Interactions between human and natural populations determine many biological responses, i.e., the loss of species as a result of habitat loss following urbanization.

Resource Accounting: The concepts of managing and accounting of individual resources have been well studied. The enterprises of agriculture, forestry, wildlife management, fisheries management, etc. all depend on basic knowledge of how the target populations respond to harvesting and hunting. The basic economic concepts for describing the payoffs and costs of these activities are also known, and in some cases (i.e., agriculture) the descriptions of market economics and biological response have been combined.

Prediction of Threshold Responses: Populations may collapse after reaching critically low or high numbers, or if important habitat or food resources are removed. Paleoecological data demonstrate that different combinations of species can be expected in different climatic regimes. Human populations and their institutions also show both continuous and discontinuous responses to environmental stresses. Environmental deterioration may have significant physiological effects on human populations.

Modeling: The scientific community has many well-developed tools for simulating the dynamics of single, and in some cases two or more interacting populations of plants and animals. Demographic models of human populations are well understood, and the interactions between economic behavior and the abundance and distribution of natural resources can be modeled on a resource-by-resource (i.e., individual crops) basis.

Research Needs

In order to advance the state of knowledge in critical areas of global change and population dynamics, the USGCRP has identified gaps in each of the areas of knowledge outlined above.

Sampling, Monitoring, and Database Development: While methodological issues do not require much attention, except in marine systems, the application of sampling and monitoring methods needs to be extended over longer periods of time for both natural and human populations. Only with longer time series of data will scientists be able to detect the projected changes due to global change over a naturally variable background of change. The empirical climate record and general circulation models have made obvious the lack of comparable, detailed ecological databases.

Dynamics of Growth and Decline: Four key unknowns in natural environments are (1) to what extent do climatic averages and variability, as well as carbon dioxide concentrations, control species composition and abundances, (2) to what degree do interspecific interactions determine the composition of the assemblage, (3) which species are the most important in any particular assemblage of species, and (4) how are species interactions likely to be altered under global change? In human-impacted environments, more understanding is needed of the consequences that global change will have on human health and on the vulnerabilities of economic institutions nationally, regionally, and worldwide. The consequences of global change for geographic distributions, dispersal and migration of populations, both human and otherwise, are poorly understood.

Resource Accounting: A more realistic accounting of the true life cycle environmental and economic costs of resource exploitation and management is necessary. Better descriptions and models of the links between energy use,

agricultural and forest management practices, land-use, human migration and gas emissions will be especially important for predicting both direct and indirect human contributions to global change.

Prediction of Threshold Responses: Greater understanding is needed of the concepts of thresholds in both economic and ecological systems. Biological and human populations susceptible to irreversible outcomes should be identified. The processes that lead to rapid changes in abundance or distribution, such as forest diebacks or fish population collapse, must be studied in relation to global change.

Modeling: Biological models of several interacting populations must be improved, coupled to the physical environment, and scaled up to larger geographic regions. Human population and economic models should be integrated with resource and biological models, in order to provide a more complete description of the interaction of resource management and the distribution and abundance of species. Simulation models must improve from being primarily descriptive to having quantitative predictive power. Analytic models must turn their attention to investigating the impacts of global change on assemblages of species.

FY 1992 Research

The agencies in the USGCRP have proposed a broad attack on these research needs. The Federal activities proposed for FY 1992 are summarized below, and the Appendix delineates each agency's FY 1992 projects.

Sampling, Monitoring, and Database Development: Using remotely sensed data from Landsat, AVHRR, 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 will continue the satellite record (i.e., MODIS), 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 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 response 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 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 at micro- to basin-scale. Both climatic stresses and physiological stress from increased UV-B flux are being investigated by EPA, USDA, DOI, and NOAA. NSF, NOAA, DOI, USDA, DOE, 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.

At a landscape scale, terrestrial disturbances (e.g., fire and windthrow) will be studied by USDA, DOE, DOI, and NSF programs. 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 and DOE 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.

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 (LTRR's) 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 decisionmaking procedures in different types of institutions and the determination of means whereby intangible costs and benefits may be more effectively integrated into decisionmaking 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 response under global change.

Modeling: On landscape-to-global scales, NSF, USDA, DOE, 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.

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.

Other Research Activities

The FY 1992 request for USGCRP activities that fall outside the four Integrating Themes is $259.2 million, an increase of $18.3 million or 7.6 percent over the FY 1991 level.

While the Integrating Themes provided a principal focus for major funding enhancements, the President's FY 1992 Budget also includes resources to maintain programmatic momentum in a number of other critical USGCRP activities. These include support for investigations in the areas of stratospheric ozone, human interactions, solid Earth processes, and solar influences.

Stratospheric Ozone

Policy Relevance: The discovery of the antarctic ozone "hole" in 1985 and the intensive research efforts during 1986-1989 to discern its cause have attracted the attention of

scientists, national and international policymakers, and the public. While unfolding a little too late to influence directly the 1987 United Nation's (U.N.) Montreal Protocol on Substances that Deplete the Ozone Layer, the results of this research strongly shaped the June 1990 amendments to the Protocol. The possible implications of the scientific questions that this newly-discovered phenomenon pose will echo in future policy debates about (1) the degree and timing of additional controls on emissions of chlorofluorocarbon (CFC) substitutes and (2) the impacts of future ozone losses on polar regions and global climate.

Research Needs and FY 1992 Program: An improved understanding of the hemispheric and global consequences of stratospheric ozone depletion in the polar regions requires studies of: (1) the photochemical reactivity and spectroscopic properties of stratospheric gases; (2) the distributions and trends of source gases in the troposphere; (3) trends in the physical structure and chemical composition of the stratosphere; (4) the interplay between chemical, dynamical, and radiative processes in the stratosphere; and (5) new instrumental techniques.

In FY 1992, NASA and NOAA will expand the Network for Detection of Stratospheric Change (NDSC) which is providing ground-based measurements of ozone and ozone-related species that are perturbed by human activities and which serves as the ground-truth and independent calibration for satellite data. The NDSC station at Mauna Loa will be completed and instruments will begin operation there and at other worldwide sites. Field campaigns and laboratory research in FY 1992 will examine how physical and chemical transformation and transport processes affect ozone losses in both polar and mid-latitude regions (NOAA, NASA, NSF, and EPA). Particular emphasis will be placed on an arctic campaign, to be conducted in collaboration with European research activities, and in preparation for a similar campaign near

Antarctica. NASA will launch the Upper Atmosphere Research Satellite (UARS) in early FY 1992 to study the coupling between the chemical, dynamical and radiative processes that control the abundance and distribution of stratospheric ozone. EPA will also continue studies related to the human health impacts of ozone depletion.

Human Interactions

Policy Relevance: Appreciation for the role of the biological, atmospheric, hydrologic, oceanic, solar, and terrestrial processes in changing the physical world is necessary, but not sufficient. The relationships between these processes and the human activities that stimulate and mediate global changes must also be understood. Without an understanding of human interactions in global environmental change that is based both on empirical observations of human behavior and on a better understanding of the consequences of human actions, the models of physical and biological processes of change will be incomplete. Such links to human behavior are required for fully effective national and international policies to deal with global change.

Research Needs and FY 1992 Program: Human activities alter ongoing physical and biological processes through the long-term cumulative effects of individual actions, whose scope is influenced by social and economic institutions and systems throughout the world. Of particular interest are those human factors which influence such issues as: greenhouse warming; deforestation; soil erosion; and the loss of biodiversity. General relationships among different human and natural systems have been long identified, but the specific processes by which individuals and institutions interact with the environment over time have not been characterized. Especially critical is identification of the ways that human, physical, and biological systems interact, often through complex feedback mechanisms.

In addition to the Human Interactions activities which support the Ecological Systems and Population Dynamics Integrating Theme, the FY 1992 Budget includes programmatic enhancements in the areas of: investigations of direct human action and indirect social, structural, and institutional influences on global change (NSF, EPA, DOE, DOI, USDA and SI); the human health impacts of ozone depletion (EPA); and education, both scientific and technical training and public education. In addition, the FY 1992 Budget includes a major enhancement in the area of Economics Research Related to Global Change which is described separately under Special Issues.

Solid Earth Processes

Policy Relevance: Besides providing the key to deciphering environments preserved in the geological record, scientific observations of solid earth processes are essential to understanding the geologic processes that are most likely to affect the life-supporting elements of the global environment. In particular, these are the processes that are active at the interfaces between the surface of the Earth's lithosphere (subaerial and submarine) and the atmosphere, hydrosphere, cryosphere (collectively known as the geosphere), and the biosphere. Some solid earth processes have a global impact, although the phenomena occur locally or regionally, such as large explosive volcanic eruptions, the gas and particulate ejecta from which can cause significant climatic cooling for short periods of time. Other globally-distributed solid earth processes have a more restricted local or regional impact, but can have severe economic and destructive effects on regions of high population density. Examples include land subsidence in coastal areas, effusive volcanic eruptions, major dust storms, tsunamis, rapidly-changing sedimentation environments or the movement of tectonic plates that may result in earthquakes. Prudent mitigation policies require a substantially better understanding of these high impact phenomena.

Research Needs and FY 1992 Program: The CEES has identified a number of high priority areas for solid earth processes investigations over the next several years, including: (1) the geological and ecological response of coastal regions to sea level rise, including coastal erosion, inundation, wetland loss, and the differentiation between climate change and tectonic processes as sources of local sea level change; (2) the effects of volcanic emissions on regional and global climate; (3) the nature and rate of the response of climatically-sensitive regions to climate change and human activities; and (4) the cause and consequences of crustal deformation processes (e.g., uplift, subsidence, and earthquakes).

The FY 1992 Budget includes specific emphasis on CEES efforts to: understand volcanic processes within the global ocean ridge system (NSF); field studies in active tectonics and volcanism (NSF, SI, DOI); investigations of the impact of sea level change on coastal regions (DOI and SI); and the development and deployment of seismic and Global Positioning System (GPS) instrumentation (NSF and DOI).

Solar Influences

Policy Relevance: The sun is the principal source of virtually all energy in the terrestrial environment. Understanding the sun in governing global change is essential for an unambiguous separation between natural and anthropogenic changes. Currently, two of the three biggest concerns in the area of global environmental change—climate warming and stratospheric ozone depletion—are dependent on the radiative environment driven by the sun.

Research Needs and FY 1992 Program: The sun is a major driver of climate and atmospheric photochemistry, e.g. ozone; is the source of energy for all photosynthesis; and is the modulator of all radionuclides in paleo-studies, e.g., ^{14}C. One high priority need of the Solar Influences Science Element is

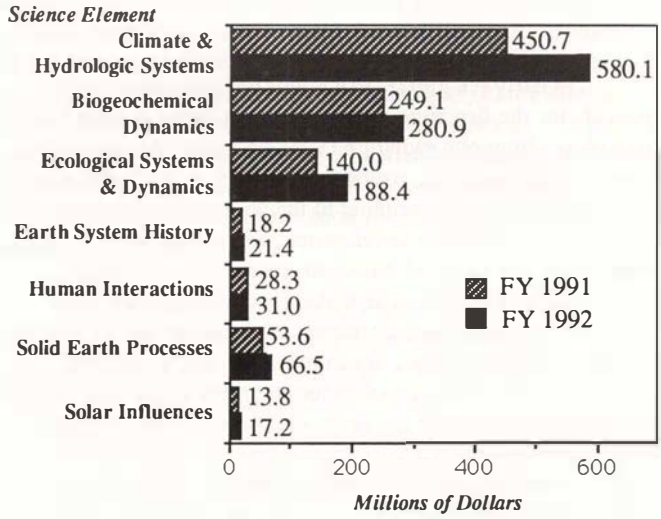
the measurement of the relatively small fluctuations in solar output and their impact on the terrestrial system. This necessitates measurements from space, in particular total irradiance for climate and spectral irradiance for photochemistry of atmospheric constituents.

In early FY 1992, UARS will be launched and will provide for the first time a comprehensive array of solar inputs, including ultraviolet radiation (UV), and simultaneous atmospheric responses, e.g., ozone fluctuations. UARS will provide important data as a forerunner to the continuous monitoring of EOS. EOS instrument development will continue in FY 1992. Complementary ground-based programs will use remote sensing to observe the state of the upper atmosphere. The Coupled Energetics and Dynamics of the Atmosphere Regions (CEDAR) and Geospace Environment Modeling (GEM) programs will continue to develop the remote sensing technologies of radar, lidar, etc., in order to observe the solar induced inputs and the upper atmosphere responses. One objective is greatly improved global circulation models with a view to understanding the role that the upper atmosphere boundary plays in controlling atmospheric dynamics.

Budget by Science Element

Table 2 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 science and impacts assessments, and the current state of both national (NAS) and international (WCRP and IGBP) scientific program development, the proposed FY 1992 activities focus primarily on the three highest priority science elements.

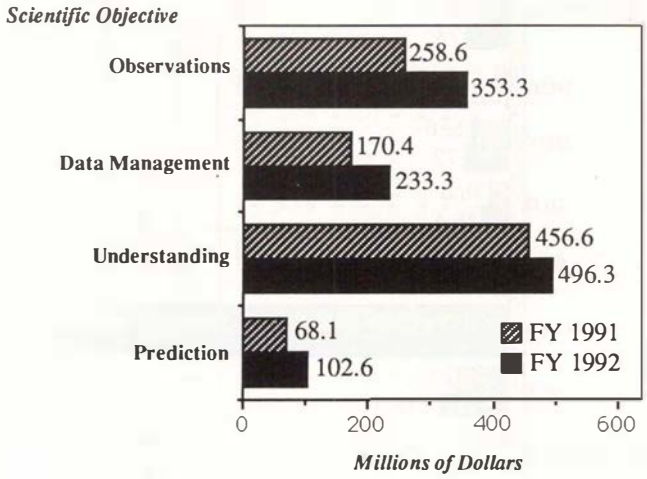
Figure 3
U.S. Global Change Research Program Budget by Science Element



Budget by Scientific Objective

Table 3 and Figure 4 show the USGCRP budget by scientific objective. The proposed FY 1992 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 databases 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.

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

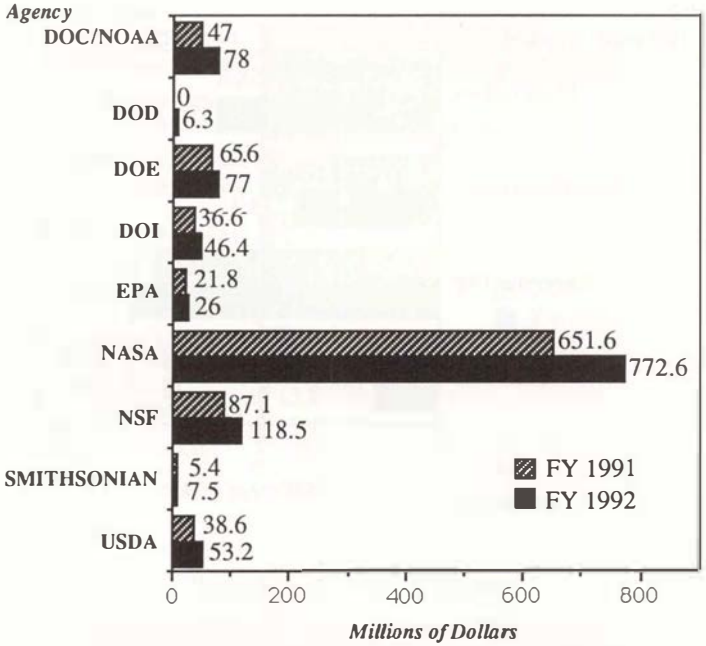


Budget by Agency

Table 2 and Figure 5 show the USGCRP budget by agency. The individual agency efforts build upon their respective scientific and technical strengths. Table 4 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.

National Oceanic and Atmospheric Administration. In FY 1992, NOAA has proposed an $78.0 million Climate and Global Change Program in support of the USGCRP. This represents a $31.0 million or 66 percent increase over FY 1991. The FY 1992 NOAA contribution involves enhancements to ongoing efforts in: operational *in situ* and satellite observation

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



programs with an emphasis on oceanic and atmospheric dynamics (including sea level), circulation, and chemistry; the development of new 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 is expected to contribute to the evolving interagency program of global change economics research.

Table 2
FY 1991-1992 U.S. Global Change Research Program Focused Budget
(Dollars in Millions)

Focused Program	Total Budget		Climate & Hydrologic Systems		Biogeochemical Dynamics		Ecological Systems and Dynamics		Earth System History		Human Interactions		Solid Earth Processes		Solar Influences	
	1991	1992	1991	1992	1991	1992	1991	1992	1991	1992	1991	1992	1991	1992	1991	1992
Agency Totals	953.7	1185.5	450.7	580.1	249.1	280.9	140.0	188.4	18.2	21.4	28.3	31.0	53.6	66.5	13.8	17.2
OOC/NOAA	47.0	78.0	37.3	61.0	7.4	10.4	0.5	2.4	1.7	2.2	0	2.0	0	0	0	0
DOD	0	6.3	0	3.8	0	0.9	0	1.0	0	0.3	0	0	0	0.3	0	0
DOE	65.6	77.0	44.2	54.0	11.0	13.0	7.4	7.3	0	0	3.0	2.7	0	0	0	0
DOI	36.6	46.4	12.7	14.2	3.0	3.0	7.2	12.7	7.5	9.1	1.6	2.1	4.6	5.3	0	0
EPA	21.8	26.0	0	0	7.2	9.3	6.3	7.4	0	0	8.3	9.3	0	0	0	0
NASA	651.6	772.6	326.3	399.8	185.7	196.1	81.8	113.1	0.0	0.0	10.2	1.8	38.3	50.2	9.3	11.6
NSF	87.1	118.5	28.1	41.8	22.4	29.9	12.5	17.9	6.2	6.8	3.6	6.8	9.9	9.8	4.4	5.5
SMITHSONIAN	5.4	7.5	0	0	0.2	0.2	2.8	4.3	1.0	1.2	0.5	0.8	0.8	0.9	0.1	0.1
USDA	38.6	53.2	2.1	5.5	12.2	18.1	21.4	22.3	1.8	1.8	1.1	5.5	0.0	0.0	0.0	0.0

Table 3
FY 1991-1992 U.S. Global Change Research Program Focused Budget By Scientific Objective
(Dollars in Millions)

Focused Program	Total Budget		Observations		Data Management		Understanding		Prediction	
	1991	1992	1991	1992	1991	1992	1991	1992	1991	1992
Agency Totals	953.7	1185.5	258.6	353.3	170.4	233.3	456.6	496.3	68.1	102.6
DOC/NOAA	47.0	78.0	12.7	20.5	7.1	12.8	17.6	26.7	9.6	18.0
DOD	0	6.3	0	1.0	0	0.5	0	3.7	0	1.1
DOE	65.6	77.0	19.4	27.0	2.0	2.0	28.5	29.8	15.7	18.2
DOI	36.6	46.4	13.6	16.5	5.6	7.1	14.8	19.2	2.6	3.6
EPA	21.8	26.0	0.2	0.4	0.1	0.2	19.4	20.9	2.1	4.5
NASA	651.6	772.6	194.4	259.5	147.7	198.8	288.2	284.0	21.3	30.3
NSF	87.1	118.5	7.7	10.1	6.0	8.5	64.5	83.8	8.9	16.1
SMITHSONIAN	5.4	7.5	1.6	2.3	0.4	0.7	3.3	4.4	0.1	0.1
USDA	38.6	53.2	9.0	16.0	1.5	2.7	20.3	23.8	7.8	10.7

Table 4
FY 1991-1992 Budget of Contributory Programs to the U.S. Global Change Research Program
(Dollars in Millions)

Focused Program	Total Budget		Climate & Hydrologic Systems		Biogeochemical Dynamics		Ecological Systems and Dynamics		Earth System History		Human Interactions		Solid Earth Processes		Solar Influences	
	1991	1992	1991	1992	1991	1992	1991	1992	1991	1992	1991	1992	1991	1992	1991	1992
Agency Totals	1120.5	1231.0	598.9	691.4	95.6	91.7	195.5	211.8	25.7	26.9	114.2	121.5	79.8	76.2	10.8	11.7
DOC/NOAA	467.7	563.2	410.1	506.9	22.7	22.8	10.3	8.9	0.1	0.1	3.9	3.9	19.7	19.7	0.9	0.9
DOD	31.0	28.9	22.1	22.7	1.1	1.1	6.0	3.9	0.0	0.0	0.0	0.0	1.8	1.2	0.0	0.0
DOE	40.4	42.3	0.0	0.0	24.7	25.1	7.0	6.5	0.0	0.0	0.0	2.0	7.7	7.7	1.0	1.0
DOI	253.3	252.9	105.4	97.6	3.4	3.4	57.9	60.4	0.3	0.3	78.3	83.2	6.3	6.3	1.7	1.7
EPA	46 .2	48.2	7.2	5.2	1.0	1.0	38.0	42.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NASA	25.3	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.3	20.0	0.0	0.0
NSF	132.5	144.4	47.2	50.3	26.6	27.1	20.8	25.3	24.3	25.0	4.9	5.1	3.6	5.6	5 1	6.0
SMITHSONIAN	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
USDA	124.1	131.1	6.9	8.7	16.1	11.2	55.5	64.8	1.0	1.3	27.1	27.3	15.4	15.7	2.1	2.1

Department of Defense. In FY 1992, DOD has proposed a $6.3 million budget for global change research. This represents the first year DOD has allocated funds as part of the focused USGCRP. In general the funds support process oriented research and modeling in high latitudes, in boundary layer dynamics, and ecological dynamics that are relevant to DOD's missions.

Department of Energy. In FY 1992, DOE has proposed a $77.0 million budget for global change research, a $11.4 million or 17.4 percent increase above FY 1991 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 climate, atmospheric, ocean, and ecosystem responses. DOE will augment research on climate modeling; studies of carbon dioxide sources in the atmosphere, oceans, and land; and impacts on vegetation and ecosystems. Focus continues on critical data needs for global change research and the climatic variables that may serve as indicators of global change; on research efforts to quantitatively describe the radiative balance and the cloud-climate feedback in the atmosphere; and on funding to provide education and training to the next generation of scientists.

Department of the Interior. In FY 1992, DOI has proposed a $46.4 million budget for global change research, a $9.8 million or 26.8 percent increase above FY 1991 enacted levels. DOI efforts include studies of: paleoclimates; interaction and sensitivity of hydrologic, ecological, and landscape systems with climate and other natural forces; arid, polar, and coastal regions and systems; volcano-atmosphere interactions; methane hydrates; changing land surface characteristics; ocean heat fluxes; social, environmental, and economic consequences of global change including human activities, water resources, coastal wetland inundation, biological species and ecological system's 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 1992, EPA has proposed $26.0 million for global change research, an increase of $4.2 million or 19.3 percent over the FY 1991 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.

National Aeronautics and Space Administration. In FY 1992, NASA has proposed $772.6 million for global change research, an increase of $121.0 million or 18.6 percent above the FY 1991 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 (e.g., the Upper Atmosphere Research Satellite, Ocean Topography Experiment, etc.) that are important precursors to the FY 1991 initiatives: Earth Probes (a series of satellite measurements prior to EOS to monitor atmospheric ozone, ocean color, precipitation in the tropics, and ocean surface winds) and the Earth Observing System (EOS). EOS will provide an integrated, comprehensive monitoring and data management program of simultaneous measurements of key global change variables. In response to several recent recommendations (i.e., the National Research Council and the recent Advisory Committee on the Future of the U.S. Space Program), an external engineering review will be undertaken during 1991 to examine additional alternatives for flying EOS instruments. In exploring these alternatives, the review shall ensure that there be no unacceptable degradation of EOS scientific objectives. In addition, $5 million has been included in NASA's FY 1992 budget to initiate the examination of the utility of remotely piloted aircraft (RPA) to serve as a precursor or

complimentary observational platform to EOS. A CEES RPA strategy report is to be developed by late spring 1991 and be submitted to the EOS engineering review for evaluation.

National Science Foundation. In FY 1992, NSF has proposed $118.5 million for global change research, an increase of $31.4 million or 36.1 percent above the FY 1991 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.

Smithsonian Institution. In FY 1992, SI has proposed a $7.5 million budget for global change research, a $2.1 million or 38.9 percent increase above FY 1991 levels. Smithsonian's research concentrates on long-term documentation of ecosystem response to environmental change. In FY 1992, SI efforts involve enhancements to ongoing research efforts 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 1992, USDA has proposed $53.2 million for global change research, an increase of $14.6 million or 37.8 percent above the FY 1991 level. USDA research efforts are focused on ground-based research programs studying agricultural, forest and range ecosystems as influenced by factors such as water balance,

atmospheric deposition, plant responses to changes in atmospheric constituents, UV-B radiation and other global change variables. Some representative studies that will focus on 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.

Budget by Federal Budget Function

Scientific, environmental, energy, security, and agricultural resources are vital to the health of our nation. Table 5 shows the USGCRP budget by Federal budget function. In FY 1992, significant increases above FY 1991 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 5
FY 1991 - 1992 U.S. Global Change Research Program
Budget by Budget Function
(Dollars in Millions)

Budget Function	Budget Function Number	1991	1992
TOTAL		953.7	1185.5
National Defense (DOD)	050	0	6.3
General Science, Space and Technology	250	738.7	891.1
NASA		651.6	772.6
NSF		87.1	118.5
Energy (DOE)	270	65.6	77.0
Natural Resources and Environment	300	105.4	150.4
DOI		36.6	46.4
EPA		21.8	26.0
DOC/NOAA		47.0	78.0
Agriculture (USDA)	300	38.6	53.2
Smithsonian	503	5.4	7.5

Special Issues

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 to achieve scientific understanding and for the ultimate attainment of a predictive capability. This requires careful arrangements for managing the enormous volumes of data and information which will result from the observational programs. Because of the critical importance of data and information management in achieving the scientific objectives, this aspect of the U.S. Global Change Research program (USGCRP) has been emphasized strongly throughout the entire Program life cycle.

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 is continuing to develop a set of data management principles. They deal with early and 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 preliminary principles are embodied within the USGCRP planning.

The primary data management focus of the FY 1992 program is to take a set of initial steps to ensure that existing and emerging key data sets are preserved and made more readily accessible. Seven agency data management proposals are identified as being of critical importance to this end.

- NASA's Earth Observing System Data and Information System (EOSDIS) will grow from 19% of the total EOS budget in 1991 to 25% in 1992. A set of early-EOS data and information activities will bring about 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 1992 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 1992, this will include continued operation of a prototype Global Land Information System with limited data sets; initiation of 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 Total Ozone Mapping Spectrometer (TOMS), Solar Backscatter Ultraviolet (SBUV), Stratospheric Aerosol Measurement (SAM-II), Stratospheric

Aerosol and Gas Experiment (SAGE-2), Earth Radiation Budget Experiment (ERBE), the Alaska Synthetic Aperture Radar (SAR) Facility, and Shuttle Imaging Radar (SIR-C).

- NOAA, in its Information Management Systems Program, supports improvements to its data holdings in order to meet the needs of the USGCRP. In 1992, this will include first 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 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 Data Bases Program will increase in FY 1992 to broaden existing projects to better meet the interdisciplinary needs of the USGCRP. These include exploratory research on value-added data and information products, e.g., 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 through, e.g., enhanced mass storage and retrieval capabilities for model data outputs.

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 1992 is $596.2 million; an increase of $112.4 million or 23.2 percent over the FY 1991 level. The proposed level of funding for EOS (observatories, instruments, data management, and scientific investigations) in FY 1992 is $336.0 million, an increase of $145.0 million over the FY 1991 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. The combination of ground- and space-based measurements is required given the temporal and spatial variability of the systems being studied, and the need to scale the processes occurring at the local level to the regional and global levels. The ground-based program is essential to interpret some of the global satellite observations (e.g., long-term trends), as well as obtain scientific information not attainable from space (e.g., trace gas fluxes). Both types of program need to be strongly supported.

U.S. scientific agencies are playing a key role in a number of interdisciplinary international scientific programs involving the land, oceans, and atmosphere, and interactions among them, that require a combination of ground- and space-based measurements for successful implementation. These programs include: World Ocean Circulation Experiment

(WOCE); Tropical Ocean-Global atmosphere (TOGA); Global Ocean Flux Studies (GOFS); Global Ocean Ecosystems Dynamics (GOED); GEWEX; IGAC; International Satellite Cloud Climatology Program (ISCCP); and International Satellite Land Surface Climatology Program (ISLSCP).

The proposed NASA space-based program is responsive to scientific and policy needs. The NASA space-based program includes: (i) EOS precursor satellite missions such as the Upper Atmosphere Research Satellite (UARS) to study the chemical, dynamical and radiative processes that control the abundance and distribution of stratospheric ozone, and TOPEX to study ocean circulation; (ii) 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; (iii) Missions Operations and Data Analysis of satellite and shuttle experiments, including the current TOMS and ERBE data, and the planned color data set; and (iv) EOS which will provide an integrated, comprehensive monitoring program of simultaneous measurements of key global change variables, coupled with a comprehensive data and information system.

Since the National Academy of Sciences (NAS) review of the USGCRP and EOS, NASA has undertaken feasibility studies of different approaches to implement EOS B, and to fly Clouds and Earth's Radiant Energy Systems (CERES) and Stratospheric Aerosol and Gas Experiment (SAGE) earlier than EOS A (for Earth radiation budget studies). NASA and CEES believe that the EOS and Earth Probes programs are essential components of the scientific program required to provide the scientific information required for national and international policy formulation with respect to key environmental issues. It should be noted that the configuration of the currently proposed EOS is scoped primarily to focus on the climate change (global warming) issue. To study climate change requires the

following instruments recently selected for the EOS A instrument complement (Advanced Spaceborne Thermal Emission and Reflection (ASTER); Multi-Angle Imaging Spectro-Radiometer (MISR); Multiband Imaging Microwave Radiometer (MIMR); Moderate-Resolution Imaging Spectrometer (MODIS Nadir/Tilt); Stick Scatterometer (STIKSCAT); Atmospheric Infrared Sounder/Advanced Microwave Sounding Unit (AIRS/AMSU); CERES; Earth Observing Scanning Polarimeter (EOSP); Lightning Imaging Sensor (LIS); Measurement of Pollution in the Troposphere (MOPPITT); and High Resolution Dynamics Limb Sounder (HIRDLS)); Active Cavity Radiometer Irradiance Monitor (ACRIM) which has been selected for a flight on a satellite of opportunity; High Resolution Imaging Spectrometer (HIRIS) which has been confirmed for development for future flight on EOS A; and the following instruments currently under consideration for EOS B (Altimeter (ALT); SAGE; Tropospheric Emission Spectrometer (TES); GPS Geosciences Instrument (GGI), and Geosciences Laser Ranging System (GLRS)). The only instruments currently being considered for EOS B that cannot be justified for studying climate change are those instruments devoted to stratospheric ozone (however, it should be noted that changes in the abundance of stratospheric ozone, especially near the tropopause, are predicted to affect tropospheric climate). This means that all of the currently planned EOS A instruments, and a significant portion of the EOS B instruments are needed for understanding climate change. The following list tracks potential EOS instruments to the areas of scientific uncertainty identified by Intergovernmental Panel on Climate Change (IPCC):

(1) *sources and sinks of greenhouse gases:* AIRS/AMSU; HIRDLS; HIRIS; ASTER; MIMR; MODIS-N/T; MOPPITT/TRACER; SAGE; STIKSCAT; and TES;

(2) *clouds and radiative balance:* ACRIM; AIRS/AMSU; CERES; EOSP; LIS; MIMR; MISR; and MODIS-N.

(3) *oceans:* ALT; CERES; MIMR; MISR; MODIS-N/T; and STIKSCAT.

(4) *land-surface hydrology:* HIRIS; ASTER; MIMR; MISR; and MODIS-N.

(5) *polar ice sheets:* ALT; GGI; and GLRS; and

(6) *ecological dynamics:* AIRS/AMSU; HIRIS; ASTER; MISR; and MODIS-N/T.

However, in response to several recent recommendations (i.e., the National Research Council and the recent Advisory Committee on the Future of the U.S. Space Program), an external engineering review will be undertaken during 1991 to examine additional alternatives for flying EOS instruments. In exploring these alternatives, the review shall ensure that there be no unacceptable degradation of the current EOS scientific objectives.

Economics Research Related to Global Change

Economics and economics research play an integral role in our ability to understand global change processes and evaluate critical national and international policy issues. Importantly:

- Economic activities play a central role in determining the level of energy and land use and industrial activity that contribute to global change.

- Economic research and methods provide an important tool for evaluating the effects on society of global changes.

- Economic considerations are important to evaluation of the costs and human consequences of actions that

might possibly be taken to alter the timing or magnitude of global change, and thus to the choice of and among policy response options.

- Economics, and the decision sciences more generally, can maximize the yield of knowledge relevant to decisionmaking by identifying which research results lie on the critical path for decisionmaking. Coordination of research efforts across the natural and social sciences to address these issues can improve the overall research program.

A full understanding of potential consequences of global environmental change, its causes, consequences, and possible responses, necessitates a thorough exploration of a broad range of economic factors. Increased recognition of the role that economics plays in global change prediction and assessment is reflected in a substantial increase in the scope and funding of the economics research effort in FY 1992. As a consequence of a thorough analysis by an ad hoc Task Force of the CEES of economics research needs, the President's FY 1992 budget proposes $17.5 million for global change economics research among seven agencies. This budget reflects an increase of $9.3 million over FY 1991 enacted funding levels. This government-wide expanded research effort, about half of which is budgeted within the current USGCRP, will undertake basic economics research related to climate change. Five main topical areas for this research, along with brief project descriptions, are outlined below. In addition an expanded NSF grants program in Global Change Economics (increased from $1.2 million in FY 1991 to $3.4 million in FY 1992) will support work across all of these areas. Short-term policy analyses, while very important, are not included. Further, this figure does not include increases in DOI's water resources research grants and NSF funding for international institutes, which will be used in part to support economics research. This research program is designed to substantially improve the depth of

insight, enhance the credibility, and reduce the uncertainty of future policy analysis efforts.

The key strategic goal of the national economics research effort is to build the economics knowledge base to enable sound policy analysis of global change issues. The economics research program will maintain an independent perspective and critically address the shortcomings of earlier work while building on its strengths. This strategic goal reflects an assessment that existing policy analyses have been hampered by a lack of fundamental economic research on resource-economy-environment interactions. The critical priorities of the economics research effort are to:

- Document economic system and sector trends that determine economic inputs and sensitivities to global change throughout the world;

- Focus studies on economic issues surrounding inputs, consequences, and responses to global change; and

- Develop interdisciplinary linkages to address issues that crosscut the natural and economic sciences.

The CEES ad hoc Task Force identified five research foci for the economics research effort.

Economic Forces Affecting or Affected by Global Environmental Change

There is a critical need for improved understanding of economic forces driving technological change and productivity growth throughout the world and of the underlying adaptive capability of economic sectors faced with climate changes. Patterns of growth may fundamentally affect global change, and may be affected by both such change and policies instituted to respond to such change. Growth in economic output,

productivity, population, and other variables needs to be considered, as well as its dependence on supplies of labor, capital, natural resources, human capital, and the state of technology and practices. Our understanding of growth determinants is generally quite detailed for industrialized countries, but requires substantial improvement for developing countries.

An ability to represent this improved understanding in economic models is also required. Modeling of economic activity affecting or affected by global change and its relationship to the world economy at large is necessary to evaluate international market and trade effects and to develop consistent scenarios and predictions of trace gas emissions and global change effects. Such economic modeling exercises serve a parallel function and a critical predicate to GCM and carbon cycle modeling exercises in the natural sciences, where improvement in methods and approaches is being vigorously pursued. Modeling exercises highlight the need to consider the full set of economic forces, responses, and adjustments, including the dynamics of economic growth and international markets for energy, capital, food, currency, labor, timber, and other goods.

The FY 1992 research budget in this area includes support for the development and refinement of aggregate global change models (DOE, EPA and USDA and NSF). In some cases, refinement will allow for more comprehensive consideration of human inputs to global change problems, while in others it will improve existing representations of human activities already included. DOE is focusing particular attention on developing countries, including China, that are expected to make a sharply rising contribution to global change, including climate change, in the future. EPA and USDA are pursuing economic studies of the international trade and competitiveness implications of response strategies and researching the augmentation of national income accounting systems to incorporate environmental considerations.

Impacts/Adaptation

Global changes could have profound impacts on the very resources and systems (e.g., water, agriculture, forests, soil, and intensively managed and natural ecosystems) which determine the health, abundance, distribution, and well-being of human beings and other species. It is necessary to develop estimates of the social, economic, and environmental impacts of global changes over the long time frames in which such changes may occur and the capacity to relate or "index" these impacts to policy variables such as increments of emissions. Factors that need to be incorporated into impacts analyses include consideration of (a) adaptive measures that may be taken even in the absence of explicit (further) government intervention; (b) technical and management innovation that may reasonably be expected to occur over these time frames that might affect the vulnerability of sectors/systems; and (c) how current policies enhance or restrict the adaptive response of individuals and private firms.

The FY 1992 research budget in this area includes support for research into issues surrounding impacts and responses to possible sea level rise (EPA, DOI, DOD); empirical studies of impacts and their valuation and responses in the agricultural, range and forestry sectors (USDA); water resource economics issues and methodology development (DOI); and the valuation of non-market ecosystem change (EPA, USDA). Further, NSF will support work in several of these areas.

The Value of Information and Decisionmaking Under Uncertainty

Identifying key variables, understanding the value of information, and framing approaches to decisionmaking under uncertainty will be of great relevance to a number of global environmental change issues. One generic policy question is whether preventive action should be taken whenever there is

any perceived risk, regardless of the value of first acquiring additional information. Another is the determination of the appropriate mix between policy intervention and additional research.

Irreversibility of species loss and other potential consequences of global change and the need to consider a time frame of 50 to 100 years or more pose special problems for national and international economics and decision science research. Researchers must re-examine discounting and the general topic of valuing future outcomes and costs, drawing on approaches from both the social and physical sciences.

These issues, which involve interdisciplinary considerations, will be pursued in a major FY 1992 initiative at NOAA. NSF will sponsor research that addresses the ways that individuals, governments, businesses, and other institutions assess the present and future values of environmental characteristics. EPA, DOI, USDA and DOE are also pursuing research in this area.

Economic Forces Shaping Technology and Practice Linked to Global Environmental Change

Technology and practice are key factors in evaluating baseline conditions, impacts, and policy proposals related to global changes. At the micro level, technologies and practices determine the rate at which inputs are transformed into outputs, including residual outputs (such as greenhouse gases) which may affect the global environment. Technologies and practices in all nations and across a wide range of sectors (including industry, energy, plant and animal agriculture, forestry, transportation, water, residential, commercial, and waste disposal) are relevant to global change issues.

Basic and applied research in the economics of technological progress is needed to develop an improved understand-

ing of the spread of technologies and practices relevant to mitigation of, or adaptation to, global change within and across countries, and how these diffusion rates and the rate of technical change itself are affected by policy, structural, institutional, legal, and financial factors, as well as by the anticipation of global change itself. This work, together with efforts to reconcile the economic and engineering approaches to forecasting the application of technology, can help to clarify the relationship between technically possible and actually achievable outcomes.

The FY 1992 research budget for this area includes support for energy technology assessments (DOE and EPA); study of technology transfer and diffusion processes (EPA, DOE, and NSF); agricultural and forestry technology issues relevant to impacts/adaptation/ and mitigation of global change (USDA). NSF is will support additional research in this area.

Policy and Policy Instrument Evaluation

Economics research can make several important contributions to establishing a foundation for policy analysis. First, economics research can address issues in strategy, gaming, negotiation, compliance and enforcement that are relevant to the global change policy process. Second, research can examine the strengths and weaknesses of the types of generic policy instruments that are potentially applicable in the global change context. Finally, research can contribute to the development and refinement of tools, such as internationally linked macroeconomic models, that will play an important role in policy analysis. The FY 1992 research budget is designed to support research efforts at NSF, DOE, DOC, and DOD.

Education, Training and Human Resources

As part of the FY 1992 USGCRP, the CEES agencies have initiated several independent but coordinated efforts that

will form the basis for and promote the development of an integrated global change education program in the future. Planning for a formal CEES Education initiative will continue during 1991 with limited funding potentially available for pilot projects in late FY 1991 and FY 1992. In addition, the education efforts of individual CEES agencies will continue to develop a qualified cadre of environmentally-oriented scientists to support the research needs of the USGCRP and its component agency programs. Graduate student development and postdoctoral opportunities will be available through NASA, NOAA, NSF, DOI, and DOE both in universities and at Federal research facilities. Emphasis in FY 1992 will be placed on interdisciplinary studies in climate and hydrologic systems, biogeochemical cycling and climate modeling and analysis. Educator Training programs will continue in DOE and DOI with a focus on training elementary and high school science teachers and also provide advanced training for undergraduate teaching faculty. In the future, CEES agencies are expected to further enhance their global change education development programs in the areas of research experiences, educator training, and environmental education and outreach activities at all levels.

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 such as TOGA; WOCE; Core Projects of the International Geosphere-Biosphere Programme (IGBP) such as the Joint Global Ocean Flux Studies (JGOFS) and the International Global Atmospheric Chemistry (IGAC) Program; 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.

This planning has been led, in many instances, by joint activities of the International Council of Scientific Unions (ICSU) and the World Meteorological Organization (WMO), especially the Joint Scientific Committee (JSC) for the World Climate Research Programme (WCRP). In addition, ICSU recently established a Scientific Committee for the International Geosphere-Biosphere Programme (IGBP) . As these programs move from planning towards implementation, leadership for oversight and coordination shifts somewhat to intergovernmental organizations which, in concert with 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 newly-established 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 joint development of mutually-supportive national contributions to international global change research projects.

The USGCRP for FY 1992 includes a new initiative to create global change research institutes, particularly to address

regional implications of global change in economically developing countries. The United States introduced this concept at the White House Conference on Science and Economics Research Related to Global Change at which the President invited other countries to join the United States in developing this initiative. The President's trip to Latin America in December 1990 provided an opportunity to advance this initiative through discussions directed at establishment of a global change research institute for the Western Hemisphere during FY 1992. Detailed discussions with interested countries will continue through 1992 under the leadership of the White House Office of Science and Technology Policy and the CEES.

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.

Evolving Priorities

The overall constraints on Federal spending associated with the 1991 deficit reduction agreement led the CEES to pursue over the next five years a more focused USGCRP than originally proposed. While giving priority in the near term to determining whether, and to what extent, human activities are changing, or will change, the global climate system, the USGCRP will continue to evolve in the future as new scientific developments and policy needs are identified. In the coming years, the CEES agencies, in concert with the national and international scientific communities, will continue to develop

and review new scientific projects to support programs such as the IGBP and WCRP.

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, etc.). Working Group 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 decisionmakers 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.

Remotely Piloted Aircraft

Five million dollars has been included in NASA's FY 1992 budget to initiate the examination of the utility of

remotely piloted aircraft (RPA) to serve as precursor or complimentary observational platforms to EOS.

An initial examination of the utility of RPAs suggests that a number of these aircraft, with a spectrum of flight characteristics, need to be developed in order to address several critical global change 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 altitude (up to 30 km) with both light and heavy instrument payloads (up to 1500 kg). No single aircraft can be expected to meet the needs of the scientific community, but a well designed ensemble can. The RPAs offer the potential to study critical Earth science processes in an unique manner using *in situ* and remote sensing instrumentation at low cost.

Several immediate research needs can be uniquely met by RPAs utilizing existing instrumentation, as well as their light-weight derivatives. Areas of Global Change Research that will be advanced by utilization of instrumented RPA's, include:

- radiation studies,
- tropical dynamics,
- meteorology,
- stratospheric/tropospheric exchange,
- polar ozone dynamics and chemistry.

An initial CEES RPA strategy report will be developed in late Spring 1991 and be submitted for review as part of the EOS engineering review.

Appendix

Fiscal Year (FY) 1991-1992 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	FY91	FY92
DOC	NOAA	Global Sea Level	3.8	4.8
DOC	NOAA	Upper Ocean Observations	3.1	5.2
DOC	NOAA	Operational Measurement	4.3	9.8
DOC	NOAA	Measurement Technique Development	0.3	1.2
DOC	NOAA	Information Management	4.6	7.0
DOC	NOAA	TOGA	6.0	6.8
DOC	NOAA	Clouds, Energy, Water	1.5	2.7
DOC	NOAA	Ocean Circulation/BGC	6.5	9.6
		(WOCE & Atlantic Climate Change)	(4.1)	(5.5)
		(Ocean Carbon & Marine Sulfur)	(2.4)	(4.1)
DOC	NOAA	Climate Modeling & Analysis	9.6	18.0
		(Near-Term Forecasting)	(0.6)	(2.2)
DOC	NOAA	Atmospheric Chemistry	5.0	6.3
DOC	NOAA	Marine Ecosystems	0.6	2.4
DOC	NOAA	Paleoclimate	1.7	2.2
DOC	NOAA	Economics Research	0.0	2.0
DOC	NOAA	TOTAL	47.0	78.0
DOD	ONR	High Latitude Dynamics	0.0	2.7
DOD	ONR	Regional Resolving Models	0.0	1.0
DOD	ONR	Boundary Layer Dynamics	0.0	0.9
DOD	ONR	Ocean Ecological Dynamics	0.0	1.0
DOD	ONR	Ocean Measurements	0.0	0.2
DOD	CRREL	High Latitude Dynamics	0.0	0.3
DOD	CRREL	Regional Resolving Models	0.0	0.2
DOD		TOTAL	0.0	6.3

Agency	Bureau	Project	FY91	FY92
DOE	OHER	Core CO_2 Research	26.4	23.1
DOE	OHER	CHAMMP	7.3	10.1
DOE	OHER	Information/Coordination	2.0	2.0
DOE	OHER	Resource Analysis	0.4	0.8
DOE	OHER	Oceans	4.0	6.0
DOE	OHER	Quantitative Link	5.0	4.8
DOE	OHER	ARM - Atmospheric Radiation Measurements	16.8	24.2
DOE	OHER	Data for Climate Modeling/Detection	1.2	2.0
DOE	OHER	Education	2.5	4.0
DOE	OHER	TOTAL	65.6	77.0
DOI	BIA	Unevenaged BIA Forests	0.0	0.1
DOI	BLM	Ecological Change in Environmentally Stressed Ecosystems of the Western & Northern U.S.	1.0	3.0
DOI	BOM	Methane Emissions from Coal Seams	0.0	0.1
DOI	BOR	Sensitivity of Hydrological Systems	1.0	1.1
DOI	BOR	Regional Studies	1.3	1.9
DOI	FWS	Coastal Wetland Change & Dynamics	1.0	1.3
DOI	FWS	Monitoring Fish & Wildlife Impacts	1.9	2.4
DOI	MMS	Coordinated Aproach to Research of Social	0.0	0.4
DOI	NPS	Integrated Studies of NPS Ecosystems	1.8	3.3
DOI	NPS	Dynamics of Coastal Systems	0.1	0.3
DOI	USGS	Paleoclimates	7.2	8.4
DOI	USGS	Land Characterization	2.0	2.0
DOI	USGS	Interaction of Climate & Hydrologic Systems	6.1	5.2
DOI	USGS	Biogeochemical Exchanges	1.1	1.1
DOI	USGS	Volcano Emissions	0.4	0.4
DOI	USGS	Sensitivity of Water Resources	1.5	1.5
DOI	USGS	Cold Regions Research	0.9	1.4
DOI	USGS	Coastal Erosion & Wetlands Pro	3.0	3.0
DOI	USGS	Climates of Arid & Semi Arid Regions	0.9	0.9
DOI	USGS	Land Data	5.1	5.6
DOI	USGS	Extramural Research	0.0	1.4
DOI	USGS	Departmental Studies	0.25	1.6
DOI		TOTAL	36.55	46.4
EPA	ORD	Emissions Research	5.0	5.5
EPA	ORD	Stratospheric Ozone	3.3	0.0
EPA	ORD	Emissions Research (Strat. Ozone)	0.0	2.7
EPA	ORD	Atmospheric Transport & Fate (Strat. Ozone)	0.0	0.7
EPA	ORD	Biospheric Transport & Fate (Strat. Ozone)	0.0	0.2

Agency	Bureau	Project	FY91	FY92
EPA	ORD	Human Health Effects (Strat. Ozone)	0.0	0.2
EPA	ORD	Ecological Effects	6.3	0.0
EPA	ORD	Terrestrial Biospheric Evaluation	0.0	4.2
EPA	ORD	Agroecosystem Effects (Strat. Ozone)	0.0	2.5
EPA	ORD	Marine Effects (Strat. Ozone)	0.0	0.7
EPA	ORD	Regional Climate	0.5	0.0
EPA	ORD	Biofeedbacks	5.7	0.0
EPA	ORD	Processes & Effects: Carbon Cycling	0.0	7.9
EPA	ORD	Marine Carbon Cycling	0.0	1.4
EPA	ORD	Tropospheric Chemistry	1.0	0.0
EPA		TOTAL	21.8	26.0
NASA	OSSA	UARS-Upper Atmosphere Research Satellite	64.0	18.2
NASA	OSSA	TOPEX-Ocean Topography Experiment	76.0	51.9
NASA	OSSA	Payload & Instrument Development	49.7	48.6
NASA	OSSA	Mission Operations & Data Analysis	39.4	56.3
NASA	OSSA	Earth Observing System (EOS) Observatories	60.0	58.5
NASA	OSSA	EOS-Science	16.0	35.0
NASA	OSSA	EOS-Instruments	79.0	159.9
NASA	OSSA	EOS-Data Information Systems	36.0	82.6
NASA	OSSA	Earth Probes	54.7	68.2
NASA	OSSA	Construction of Facilities	9.0	17.0
NASA	OSSA	Space-based Subtotal	483.8	596.2
NASA	OSSA	Solid Earth Science	7.8	11.9
NASA	OSSA	Interdisciplinary Research & Analysis	12.4	2.5
NASA	OSSA	Suborbital Research Observations	20.2	20.3
NASA	OSSA	Model & Data Hydrology/ Circulation/Physical Climate	28.0	28.0
NASA	OSSA	Model & Data Solid Earth/ Ecological Systems/Biogeochemical Dynamics	16.3	17.0
NASA	OSSA	Hydrologic/Circulation/Physical Climate Processes	31.8	34.2
NASA	OSSA	Upper Atmosphere Research Program	28.3	30.9
NASA	OSSA	Laser Network	2.4	3.3
NASA	OSSA	Ecosystem Dynamics and Biogeochemical Processes	20.6	23.3
NASA	OSSA	RPA's	0.0	5.0
NASA	OSSA	Ground-based Subtotal	167.8	176.4
NASA		TOTAL	651.6	772.6

Agency	Bureau	Project	FY91	FY92
NSF	GEO	ARCSS-Arctic System Science	7.7	9.4
NSF	GEO	CHP-Continental Hydrologic Processes	0.9	1.1
NSF	GEO	GEWEX-Global Energy & Water Cycle Experiment	0.1	0.4
NSF	GEO	ICMAP - Integrated Climate Modeling, Analysis and Prediction	0.0	3.5
NSF	GEO	Role of Clouds	0.0	0.4
NSF	GEO	TOGA-Tropical Oceans Global Atmosphere	10.6	14.7
NSF	GEO	WOCE-World Ocean Circulation Experiment	12.3	16.5
NSF	GEO	GTCP-Global Tropospheric Chemistry Program	11.0	13.5
NSF	GEO	JGOFS- Joint Global Ocean Flux Study	10.7	14.7
NSF	GEO	Ozone Depletion/UV Effects	5.6	5.6
NSF	GEO	Antarctic Ecosystems	1.5	2.5
NSF	BBS	EROC - Ecological Rates of Change	2.6	3.4
NSF	GEO	GLOBEC-Global Ocean Ecosystems Dynamics	1.4	3.5
NSF	GEO/BBS	LMER-Land-Margin Ecosystems Research	2.1	2.8
NSF	BBS	WEV-Water-Energy-Vegetation	0.0	0.1
NSF	GEO	Abrupt Climate Change	0.1	0.4
NSF	GEO	Geological Record of Global Change	1.5	1.8
NSF	BBS	Economics Research on Global Change	1.2	3.4
NSF	BBS	Human Dimensions of Global Environmental Change	2.4	3.4
NSF	GEO	Geodynamics	5.7	5.7
NSF	GEO	RIDGE-Ridge Interdisciplinary Global Experiment	3.9	3.9
NSF	GEO	CEDAR-Coupling, Energetics, & Dynamics of Atmospheric Regions	4.1	4.7
NSF	GEO	GEM-Geospace Environment Modeling	0.3	0.8
NSF	GEO	Geosystems Databases	1.2	2.1
NSF	GEO/BBS	Global Change Education & Training	0.2	0.2
NSF	GEO	International Institutes	(0.0	2.0)*
NSF		TOTAL	87.1	118.5

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

SI	STRI	International Tropical Forest Dynamics	0.2	0.4
SI	STRI	Long-Term Environmental Monitoring	0.4	0.6
SI	STRI	Tropical Forest Canopy	0.4	0.4
SI	STRI	Biotic Responses to Atmospheric Change	0.1	0.1
SI	SERC	Chesapeake Bay Global Change	0.4	1.3
SI	NMNH	Amazonia Biological Diversity	0.7	0.8

Agency	Bureau	Project	FY91	FY92
SI	NMNH	Caribbean Coral Reef Ecosystems	0.3	0.4
SI	NZP	Global Change/Migratory Birds	0.3	0.3
SI	STRI	Tropical Agroforestry Program	0.2	0.2
SI	NMNH	Human Ecological History	0.1	0.4
SI	IC	SI/Man in the Biosphere	0.1	0.1
SI	NZP	International Conservation Biology	0.1	0.1
SI	SAO	Space Geodesy/Global Change	0.1	0.1
SI	NASM	Global Change in Earth's Drylands	0.3	0.3
SI	NMNH	Nile Delta and Global Change	0.1	0.1
SI	NMNH	Global Volcanism Program	0.3	0.4
SI	NMNH	Paleoecological Effects of Climate Change	1.0	1.2
SI	SAO	Atmospheric Chemistry	0.2	0.2
SI	SAO	Solar Studies/Global Change	0.1	0.1
SMITHSONIAN		TOTAL	5.4	7.5
USDA	ARS	Biological Response to UV-B	0.7	0.7
USDA	ARS	Ecosystem Modeling	2.0	2.0
USDA	ARS	Biogeochemical Fluxes	2.0	2.0
USDA	ARS	Ozone Effects	0.4	0.4
USDA	ARS	Scale Effect of Hydro. Proc.	0.0	1.5
USDA	ARS	Pred. Impact on Sustain. Wtr	0.0	1.5
USDA	ARS	Time Change in Soil Carbon	0.0	1.0
USDA	CSRS	Stratospheric Ozone Depletion	9.4	9.4
USDA	CSRS	UV-B Monitoring Network	0.0	3.0
USDA	CSRS	Energy-Methane Sources, Biomass Fuels	0.0	2.0
USDA	SCS	Pedosphere-Paleoecology	0.8	0.8
USDA	SCS	Pedosphere-Processes	0.7	0.7
USDA	FS	Energy, Water, Carbon & Nutrient Cycles	7.5	8.0
USDA	FS	Species Life History	6.7	7.0
USDA	FS	Water Yield, Erosion & Sedimentation	2.3	2.8
USDA	FS	Fire Severity	2.3	2.5
USDA	FS	Aquatic Ecosystems & Fisheries Habitat	1.4	1.3
USDA	FS	Wildlife/Domestic Species Interactions	0.6	0.9
USDA	FS	Microbes, Plant Pathogens & Insects	1.8	1.4
USDA	FS	Economics	0.0	1.5
USDA	ERS	Econ. Sys. & Global Change	0.0	0.5
USDA	ERS	Economics	0.0	2.3
USDA		TOTAL	38.6	53.2

Agency Acronyms

DOC	NOAA	National Oceanic and Atmospheric Administration
DOD	ONR	Office of Naval Research
	CRREL	Cold Regions Research and Engineering Laboratory
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
	MMS	Minerals Management Service
	NPS	National Park Service
	USGS	U.S. Geological Survey
EPA	ORD	Office of Research & Development
NASA	OSSA	Office of Space Science & Applications
NSF	BBS	Biological Behavioral & Social Sciences Directorate
	GEO	Geosciences Directorate
SI	STRI	Smithsonian Tropical Research institute
	SERC	Smithsonian Environmental Research Center
	NMNH	Natural Museum of Natural History
	NZP	National Zoological park
	IC	International Center
	SAO	Smithsonian Astrophysical Observatory
	NASM	National Air and Space Museum
USDA	ARS	Agriculture Research Service
	CSRS	Cooperative State Research Service
	ERS	Economic Research Service
	FS	Forest Service
	SCS	Soil Conservation Service

The upper figure is a map of mean sea level. This map of sea level was obtained from the altimeter which flew aboard the 3-month Seasat mission in 1978. Sea level was measured by Seasat with a 5-centimeter (2-inch) precision and a 65-cm (26-in) accuracy. Color changes occur at 2.5-m (8-foot) intervals, with blues indicating surface lows and yellows indicating highs. The textural characteristics of the surface are similarly highlighted through illumination from the east. Major features again include the Mid-Atlantic Ridge (1); the deep-ocean trenches of the Pacific (2, 3); and the island-seamount chains (4, 5). Fracture zones (6), narrow linear troughs which sometimes extend for thousands of kilometers across an ocean basin, are particularly well resolved in this sea-level map.

The lower figure shows bathymetry. Both color and shading have been used to indicate variations in the bathymetry. Changes in color occur at 500-m depth intervals, with blues indicating deep areas and yellows indicating shallow. Shading is superimposed on this color map to simulate illumination of the sea floor from the east, thus highlighting features with a north/south orientation. The dominant features in this map are: the mid-ocean ridges which rise to within 2000 m (6600 ft) of the ocean surface, one such example being the Mid-Atlantic Ridge (1); the deep-ocean trenches, which can be deeper than 10,000 m (33,000 ft) and are most evident in the northern and western Pacific (2, 3); and the chains of islands and seamounts such as the Hawaiian-Emperor system in the North Pacific (4) and the Louisville Ridge system in the South Pacific (5).

The U.S. Global Change Research Program