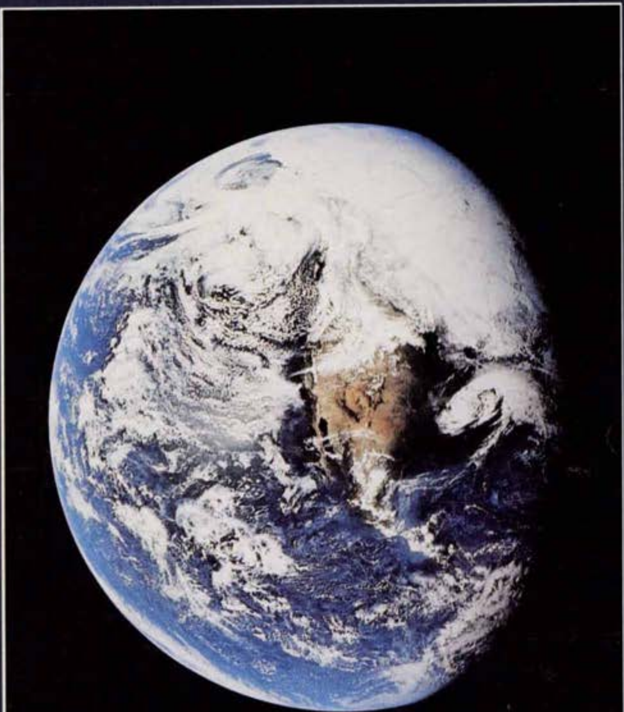
Our Changing Planet:

The FY 1991
U.S. Global Change Research Program



A Report by the Committee on Earth Sciences

To Accompany the
U.S. President's Fiscal Year 1991 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

Committee on Earth Sciences

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

MEMBERS OF CONGRESS:

I am pleased to forward with this letter "Our Changing Planet: The FY 1991 U.S. Global Change Research Program," a report by the Committee on Earth Sciences of the Federal Coordinating Council for Science, Engineering, and Technology to accompany the President's Fiscal Year 1991 Budget.

The report outlines an accelerated, focused research strategy designed to reduce key scientific uncertainties and to develop more reliable scientific predictions upon which sound policies and responses to global change can be based. Because of the importance of this area, the President is proposing a 57 percent increase in the budget for this effort for FY 1991.

The research program presented here is a key component of the President's overall approach to the global change issue. This approach has, as its central goal, the provision of a sound scientific basis for developing national and international policy on global change. The President has called for an expanded schedule of international collaboration on research, monitoring, data exchange, and a new Framework Convention on climate change. This comprehensive approach recognizes the profound economic and social implications of responding to global environmental changes and maintains U.S. leadership on this issue.

The Committee on Earth Sciences' report outlines a careful blend of ground- and space-based efforts in research, data gathering, and modeling activities 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 which produced it provide an exemplary model of a coordinated, integrated research strategy and a sound basis for planning. Chairman Dallas Peck, Vice Chairman Robert Corell, and their interagency committee members, associates, and staff have done an excellent job and are to be commended.

Sincerely,

D. Allan Bromley
Director

To obtain a copy of this document – send request to:

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Executive Summary

- Although the Earth has been changing for millions of years, dramatic recent changes such as antarctic ozone depletion demonstrate that human activities are affecting the Earth system.

- Recognizing the profound economic and social implications of responding to global environmental changes, the President has set in motion a comprehensive process designed to continue U.S. leadership on this issue. This includes an accelerated, focused research effort; active participation in international collaborative efforts intended to culminate in a Framework Convention; and a comprehensive review of potential policies and their implications.

- As the research component of this process, the U.S. Global Change Research Program is designed to reduce key scientific uncertainties and to develop more reliable scientific predictions upon which sound policy strategies and responses can be based.

- An improved predictive model of the integrated Earth system and a better understanding of human interactions with this system will provide direct benefits by anticipating and planning for impacts on commerce, agriculture, energy, resources utilization, and human safety.

- Because of the high priority attached to the U.S. Global Change Research Program, the President is proposing $1,034 million for this research effort in the FY 1991 budget, a $374.8 million or 57 percent increase over the FY 1990 level.

- This proposed budget will significantly expand research, data gathering, and modeling activities with both near- and long-term scientific and public policy benefits. It includes a carefully balanced mix of ground- and space-based research efforts that are essential given the variability of the phenomena being studied and the need to scale local processes to regional and global levels.

- For the ground-based program, the proposed budget will initiate multi-agency research thrusts in several critical areas, including the role of clouds in controlling climate, fluxes of greenhouse gases, resource responses to global change, past changes in the Earth system, and the role of human activities in global change.

- For the space-based program, the proposed budget will initiate the development of the NASA Earth Observing System, a key element in "Mission to Planet Earth," which will provide the centerpiece of an integrated international satellite program for monitoring global change, coupled with a comprehensive data and information system.

- This report summarizes the key features and budget of the proposed U.S. Global Change Research Program for FY 1991. A more detailed FY 1991 research plan will be released in the spring of 1990.

- The research program was developed by the Committee on Earth Sciences of the Federal Coordinating Council for Science, Engineering, and Technology, in 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.

Introduction

World leaders are taking an increased interest in 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 in recent decades in the Sahel starkly reveals the human tragedy that can occur in marginal-subsistence zones of a changing planet. Furthermore, the very recent linking of the antarctic ozone "hole" to man-made chlorofluorocarbons and the current debate over humanity's role in the greenhouse effect have placed the environment high on the national and international agenda.

In virtually all of these issues, the salient feature is the significant scientific uncertainty associated with predicting the behavior of the coupled ocean-atmosphere-land system. The formidable costs associated with addressing environmental change require that policy decisions be based on adequate scientific knowledge. To provide this knowledge, the U.S. Global Change Research Program has been created as a key component of the President's overall approach to global environmental change. Because of the priority attached to this issue, the President is requesting $1,034 million for the research program in FY 1991, an increase of $374.8 million or 57 percent over the FY 1990 level.

The present document is the second in a series of overviews that accompany the President's annual budget to the Congress. It highlights the Program's FY 1991 research activities and budget developed by the Committee on Earth Sciences (CES) of the Federal Coordinating Council for Science, Engineering, and Technology.

The CES activities of the past year began with the publication in January 1989 of *Our Changing Planet: A U. S. Strategy for Global Change Research*. Following this strategic plan, the CES prepared *Our Changing Planet: The FY 1990 Research Plan* (July 1989), which reviewed the Earth system changes that have occurred in the past; the forces that are at work today;

and the strengths and weaknesses in current scientific understanding. It also described the highest priority interdisciplinary research needs, agency roles, and new FY 1990 research initiatives.

The FY 1990 Research Plan was reviewed by the National Academy of Sciences, the American Geophysical Union, and others, all of whom strongly endorsed the Program's holistic approach to understanding the Earth system. The *Plan* is also consistent with the concepts outlined by the International Geosphere-Biosphere Programme and the World Climate Research Programme.

While recognizing the need for a comprehensive research and modeling effort, the FY 1991 Program also focuses on the scientific issues underlying current and future policy questions, including: Should the "Montreal Protocol on Substances that Deplete the Ozone Layer" be strengthened? Has a global warming signal been detected, and what are the relative contributions from natural processes and human activities? What will the climate of the coming century be like, and how will it impact agriculture, forestry, habitation, and water and energy supply and use?

Furthermore, the present document shows how this integrated interdisciplinary program has begun to address such crosscutting activities as understanding the carbon cycle, data management, education, and emerging disciplines.

A comprehensive FY 1991 research plan will be published in the spring of 1990.

Planning the FY 1991 Program

In *The FY 1990 Research Plan*, the CES established the following goal and objectives for the U.S. Global Change Research Program:

Goal:

To establish the scientific basis for national and international policymaking relating to natural and human-induced changes in the global Earth system.

Objectives:

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.

To develop integrated conceptual and predictive Earth system models.

Planning Framework

Each year the CES will review the Program to ensure that it continues to aggressively address its goal and objectives. This process began in mid-July 1989, when CES evaluated individual agency initiatives relative to ongoing programs and the priority and evaluation framework outlined later in this section.

At a series of meetings over the ensuing months, agency representatives developed a final recommendation on the content and resource requirements for the FY 1991 Program. Subsequently, during the fall of 1989, there were extensive program reviews and discussions that led ultimately to the FY 1991 Program and budget summarized herein.

As part of these deliberations, the CES has forged increasingly effective partnerships among the Federal agencies and with the scientific community. These partnerships, the need to integrate science into the policy process, and the focus on interdisciplinary science have become the "Basic Tenets" (see box on page 7) of the CES cooperative planning process.

Priority Framework

In the preparation of *The FY 1990 Research Plan*, the CES created and implemented a multi-level priority-setting framework that was used to focus and integrate the program development and budget proposals. This framework contains three levels of priorities for the U.S. Global Change Research Program, diagrammed in Figure 1. These strategic, integrating, and science priorities focus on those research questions that will produce significant early improvements in understanding and modeling the interactive Earth system. For example, there is little disagreement that a major shortcoming of existing general circulation models is their inability to simulate the role of clouds and convective processes accurately; hence, that research is the highest priority in the Climate and Hydrologic Systems element. However, concurrent progress in high priority activities in all science elements is necessary for the Program to achieve its overall goal, although not all will receive equal emphasis.

Evaluation Criteria

Within each science element, the CES evaluated FY 1991 research initiatives, taking into account the priorities and several evaluation criteria (see box on page 10). These criteria provided a framework for designing the specific project-by-project structure that constitutes the Program (see Appendix for project listing).

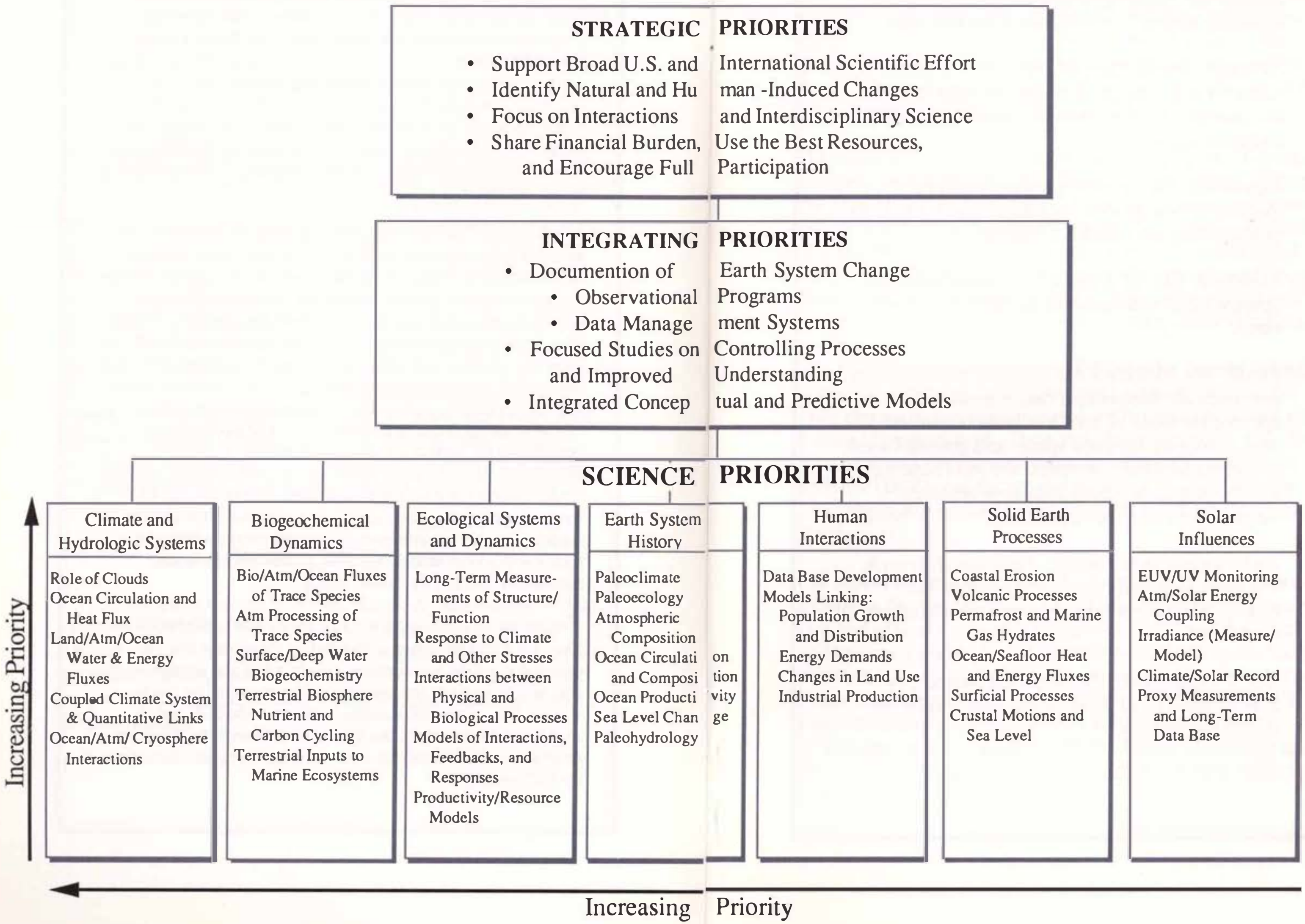
The CES Process: Basic Tenets

- ***Integrate Science into the Policy Process.*** The need for effective relationships between the policy processes of governments and the underlying science of environmental issues has always been recognized and central to the U.S. Global Change Research Program. A process for policy development has evolved within the Executive Branch that directly involves the CES, including (i) it being the focal point for the development and coordination of U.S. scientific programs for global change, both domestically and internationally, and (ii) ensuring that the results of these scientific efforts provide the foundation for rational policy debate and effective action.

- ***Maintain a Partnership Among All Participants.*** A partnership has evolved among the CES members and between CES and the non-Federal research community through the relevant Committees and Boards of the National Academy of Sciences (NAS), notably the Committee on Global Change (CGC). Within CES, there has been a conscious effort not to designate "lead" agencies. Leadership is distributed among the agencies, with each contributing its strengths to the planning, documentation, review, and implementation process. This partnership concept is fundamental to the operation of the CES. The same philosophy is operative in the parallel planning relationship with the NAS, including joint meetings, program reviews, and exchange of ideas for developing implementation strategies. In addition, the CES has interacted with (i) the international scientific community and agencies of other governments, (ii) several intergovernmental bodies with global change concerns, (iii) the environmental community, and (iv) the private sector.

- ***Focus on Interdisciplinary Science and Interactions.*** The CES science program is founded on the premise that the essential scientific questions can only be addressed through interdisciplinary research on the interacting components of the Earth system. This is also the scientific strategy of the CGC and its international counterpart, the International Geosphere-Biosphere Programme (IGBP), thereby further strengthening the interactions of the CES and CGC.

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



The CES Evaluation Criteria

- ***Relevance/Contribution.*** The research must address the overall goal and one or more of the three key scientific objectives of the Program.

- ***Scientific Merit.*** The proposed work must be scientifically sound and of high priority, and be the product of a documented scientific planning and review process.

- ***Readiness.*** The level of planning must be mature, of high quality, and the research likely to produce vital and needed advances.

- ***Linkages.*** The CES looks for established inter-agency, other national, and international connections.

- ***Costs.*** The CES considers whether the identified resources are adequate; if they represent an appropriate share of total available resources (e.g., a balance between space- and ground-based program elements); prospects for joint funding; and the degree to which long-term resource implications have been evaluated.

- ***Enhancements to Existing Program Research.*** The highest priority existing programs will receive adequate support before new initiatives are funded.

- ***Agency Approval.*** The proposed program or activity must have policy-level approval by the submitting agency.

Agency and Organizational Roles

At the outset of the Program, the CES developed a set of role statements that specifically define each agency's respective role in the Program (see *The FY 1990 Research Plan,* Appendix A). In developing the FY 1991 Program, that process of role definition has been extended. The current status of participation in the Program by CES agencies and other Federal organizations has three categories:

(1) ***Agencies whose budget initiatives are in the "focused" category and hence are detailed in this document.*** These are the Department of Commerce, National Oceanic and Atmospheric Administration (DOC/NOAA), Department of Energy (DOE), Department of the Interior (DOI), Environmental Protection Agency (EPA), National Aeronautics and Space Administration (NASA), National Science Foundation (NSF), and the United States Department of Agriculture (USDA).

(2) ***Agencies whose programs fall into the "contributing" category.*** These agencies' programs support many of the science elements, but were initiated for reasons other than the focused Program goal. They include the agencies with focused programs and the research agencies of the Department of Defense (DOD) (including the Office of Naval Research, the Oceanographer of the Navy, and the U.S. Army Corps of Engineers).

(3) ***Agencies and offices of the Executive Branch that contribute to the overall guidance of the Program.*** These agencies and offices contribute to the architecture of the Program and are key vehicles for coordinating and linking the Program with overall national and international policy on global change. These include the Council on Environmental Quality (CEQ), Departments of State (DOS) and Transportation (DOT), Office of Management and Budget (OMB), Office of Science and Technology Policy (OSTP), and the White House Office of Policy Development.

Benefits

The U.S. Global Change Research Program is founded on the premise that effective strategies to address environmental issues can be built only on sound scientific information.

Therefore, a hallmark of the Program strategy is linking the U.S. scientific program for global change to the policy process, including:

- Predicting the magnitude and timing of environmental variations, thereby providing the means to plan or avoid their impacts.

- Separating natural changes from human-induced changes, thereby balancing regulatory needs with economic and social development and providing the ability to focus on those parts of the problem that are traceable to human intervention.

Specifically, this is accomplished by supporting a robust, prioritized research effort that can address important policy issues (see box on page 13) and address public needs for predicting and dealing with environmental change through:

(i) ***Providing Timely Information*** – making available the results of scientific research through special briefings and other information products for the Congress, the Executive Branch, and others immediately after new insights are obtained;

(ii) ***State of the Science Assessments*** – providing periodic assessments of the "state of the science" in the critical areas of global change (as has been done regarding the stratospheric ozone layer), employing both domestic and international mechanisms, such as the Committees of the NAS and the Intergovernmental Panel on Climate Change (IPCC);

Benefits of the U. S. Global Change Research Program: Examples

- ***Greenhouse Gases.*** A better understanding of the processes, both natural and human-influenced, that govern the sources and fates of greenhouse gases will provide a basis for analyzing integrated control strategies and cost-benefit analyses.

- ***Ozone Depletion.*** Maintaining the "Montreal Protocol on Substances that Deplete the Ozone Layer" will require an improved knowledge of the mechanisms controlling the stability of the stratospheric ozone layer.

- ***Energy.*** Establishing links between carbon dioxide emissions and atmospheric abundances with energy policy scenarios will facilitate the assessment of different energy technologies.

- ***Agriculture/Ecosystems.*** Better knowledge of the linkages of crops, forests and other ecosystems to environmental conditions will enhance the ability to make sound decisions regarding food security, forest management, and conservation of natural resources, including crop selection, reforestation, and deforestation practices.

- ***Water Policy.*** A more complete knowledge of the interaction of the climate and hydrological cycles will help resolve issues involving water supply and demand and will allow better planning for the allocation of water resources during extreme events.

- ***Sea Level.*** Elucidation of the processes that control sea level will provide the predictive capability to guide policies regarding coastal human settlements and wetlands.

(iii) ***Regular Prediction/Forecasting Products*** - providing a line of information products that address three time scales: seasonal, interannual, and interdecadal.

- ***Seasonal Projections*** - It is expected that research already under way (including developments from the sciences associated with weather forecasting) will lead to seasonal forecasts (i.e., 30- to 60-day projections) within three to five years. These products will likely be derived from the existing weather forecasting systems operating throughout the countries of the world. Ocean forecasting is in an earlier state of development and will require increased effort to achieve this goal.

- ***Interannual Projections*** - The advent of a greatly improved understanding of how the tropical ocean induces changes in heating patterns within the atmosphere (El Niño and the Southern Oscillation) is leading toward one of the next realizable lines of predictive products. It is expected that within about 10 years regular assessments and forecasts will be produced quarterly, each providing three- to six-month forecasts, a one-year prognosis, and a two-year outlook of interannual climate variability for selected climatic processes.

- ***Interdecadal Projections*** - It is expected that prediction of selected climatic processes on interdecadal (ten to twenty years) time scales will emerge during the coming decade. The products will consist of interpretive reports and model predictions. This process is beginning with the science assessment of the IPCC and the Second World Climate Conference in late 1990.

In summary, the overall benefits of the Program are substantial: (i) providing critical data to minimize economic or other adverse impacts by supporting prudent near-term actions where justified, while accelerating the development of more reliable scientific understanding on which to base long-term policies; (ii) contributing to the Nation's environmental leadership and credibility, both domestically and internationally; and (iii) serving as a catalyst for similar scientific commitments from other nations.

Research Program and Budgets

The following sections summarize the FY 1991 activities and budgets of the U.S. Global Change Research Program in the seven interdisciplinary science elements, by agency, by scientific objective including data management, by Federal budget function, and by the balance between space- and ground-based components. Because of the complex nature of the Program, examples of important research, data collection, and modeling activities will be mentioned along with how they address the research priorities and related policy-relevant questions.

Budget Overview

Table 1 shows the U.S. Global Change Research Program budget proposal by science element, by agency, and by scientific objective. In FY 1990 funding for the U.S. Global Change Research Program is $659.3 million.* The President's FY 1991 budget proposes a funding level of $1,034 million, a $374.8 million (57 percent) increase over the FY 1990 level. Table 2 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.

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* The FY 1990 Program as outlined in the President's FY 1990 Budget to Congress was $190.5 million (see *Our Changing Planet: A U.S. Strategy for Global Change Research*, January 1989). The FY 1990 Program was adjusted to $659.3 million over the past year reflecting subsequent FY 1990 Appropriations actions by the Congress and the reevaluation of "focused" and "contributing" programs. The bulk of this increase is due to the transfer of several NASA programs from the "contributing" category.

Budget by Science Element

This section summarizes the FY 1991 activities in the seven interdisciplinary science elements and data management. Figure 2 shows the FY 1990 enacted and FY 1991 proposed budgets for the U.S. Global Change Research Program by science element. At this time the U.S. Global Change Research Program focuses primarily on the three highest priority science elements: Climate and Hydrologic Systems, Biogeochemical Dynamics, and Ecological Systems and Dynamics. However, the Program maintains an appropriate level of effort in all seven science elements consistent with the policy needs, science priorities, and the current state of scientific program development.

Figure 2
U.S. Global Change Research Program Budget by Science Element

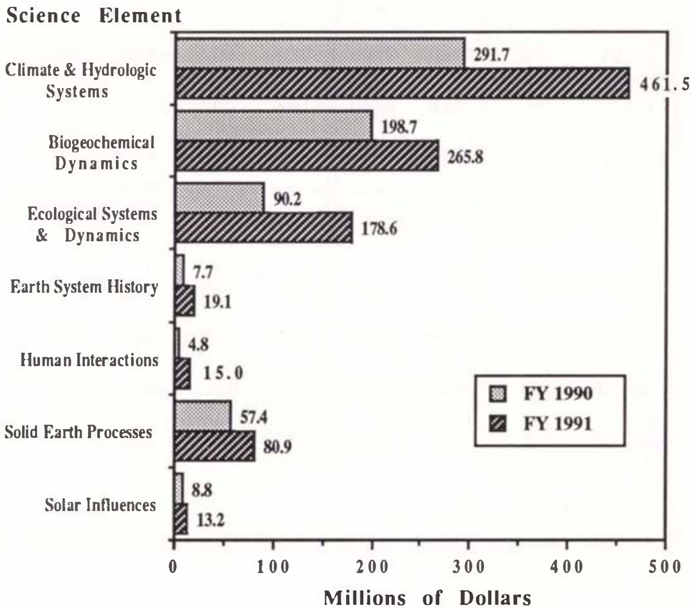


Table 1

FY 1990-1991 U. S. Global Change Research Program Focused Budget

(Dollars in Millions)

Focused Program	Total Budget		Climate & Hydrologic Systems		Biogeochemical Dynamics		Ecological and Systems Dynamics		Earth System History		Human Interactions		Solid Earth Processes		Solar Influences	
	FY90	FY91	FY90	FY91	FY90	FY91	FY90	FY91	FY90	FY91	FY90	FY91	FY90	FY91	FY90	FY91
Agency Totals	659.3	1034.1	291.7	461.5	198.7	265.8	90.2	178.6	7.7	19.1	4.8	15.0	57.4	80.9	8.8	13.2
DOC/NOAA	18.0	87.0	14.2	67.6	3.3	13.5	0.0	4.9	0.5	1.0	0.0	0.0	0.0	0.0	0.0	0.0
DOE	50.0	66.0	32.0	44.0	7.0	9.0	9.0	10.0	0.0	0.0	2.0	3.0	0.0	0.0	0.0	0.0
DOI	13.3	43.7	4.9	12.2	0.8	2.0	0.9	10.3	2.4	8.0	0.9	5.3	3.4	5.9	0.0	0.0
EPA	13.2	26.0	1.0	3.3	2.5	3.1	9.7	19.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NASA	488.6	661.0	221.4	302.5	162.2	198.3	51.0	90.0	0.0	0.0	0.0	0.0	47.7	63.0	6.3	7.2
NSF	55.0	103.0	16.8	29.8	20.2	32.2	3.5	8.5	4.5	9.0	1.2	5.5	6.3	12.0	2.5	6.0
USDA	21.2	47.4	1.4	2.1	2.7	7.7	16.1	35.3	0.3	1.1	0.7	1.2	0.0	0.0	0.0	0.0
Scientific Objective																
Observations	137.2	255.0	89.1	148.9	17.2	38.9	14.1	39.6	0.0	0.2	0.0	2.2	13.1	20.8	3.7	4.4
Data Management	65.2	129.4	32.9	64.0	21.2	34.7	5.5	17.7	0.5	2.2	0.4	1.0	3.8	8.8	0.9	1.0
Understanding	409.7	560.0	143.1	200.3	148.1	176.2	65.5	103.2	6.1	13.1	2.9	10.6	40.5	50.1	3.5	6.5
Prediction	47.2	89.7	26.6	48.3	12.2	16.0	5.1	18.1	1.1	3.6	1.5	1.2	0.0	1.2	0.7	1.3

Table 2
FY 1990-1991 Budget of Contributory Programs to the U.S. Global Change Research Program

(Dollars in Millions)

Contributing Program	Total Budget		Climate & Hydro-logic Systems		Biogeochemical Dynamics		Ecological and Systems Dynamics		Earth System History		Human Interactions		Solid Earth Processes		Solar Influences	
	FY90	FY91	FY90	FY91	FY90	FY91	FY90	FY91	FY90	FY91	FY90	FY91	FY90	FY91	FY90	FY91
Agency Totals	853.8	918.2	432.4	443.1	63.6	80.1	209.1	234.4	24.3	25.7	71.4	77.4	44.9	47.3	8.1	10.2
DOC/NOAA	300.6	315.9	254.2	268.0	10.4	10.4	36.0	37.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DOD	31.2	31.0	22.3	22.1	1.1	1.1	6.0	6.0	0.0	0.0	0.0	0.0	1.8	1.8	0.0	0.0
DOE	39.3	39.5	0.0	0.0	21.8	22.4	8.6	8.4	0.0	0.0	0.0	0.0	7.9	7.7	1.0	1.0
DOI	225.1	227.7	97.4	91.0	2.7	2.9	51.4	54.9	0.4	0.4	65.1	70.4	6.1	6.1	2.0	2.0
EPA	83.3	50.6	11.0	8.3	1.6	2.0	70.7	40.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NASA	24.7	25.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.7	25.3	0.0	0.0
NSF	124.2	132.5	45.2	47.2	23.1	26.6	18.9	20.8	23.8	24.3	4.6	4.9	3.5	3.6	5.1	5.1
USDA	25.4	95.7	2.3	6.5	2.9	14.7	17.5	66.5	0.1	1.0	1.7	2.1	0.9	2.8	0.0	2.1

Climate and Hydrologic Systems

Table 1 shows that the FY 1991 request for this element is $461.5 million, a $169.8 million or 58 percent increase over the FY 1990 level.

The increasing abundances of greenhouse gases in the Earth's atmosphere are altering the radiative balance of the planet. However, the impact on the climate is uncertain. The response of the Earth's climate is strongly tied to the natural variability of the climate and hydrologic systems, including the atmospheric, oceanic, cryogenic, and land surface processes that govern the distribution of temperature, moisture, clouds, and rainfall. Effective policy formulation requires quantification of the natural and human-induced variability in the climate and hydrologic systems, and reliable predictions of the magnitude and timing of regional and global changes in response to the increasing abundances of greenhouse gases.

The FY 1991 research efforts listed below reflect the Program's research priorities (see Figure 1) and involve the following policy-relevant questions:

(1) *What is the role of clouds in the Earth's radiation and heat budgets?*

Clouds and water vapor play a pivotal role in the Earth's radiation and heat budgets. They control the amount of solar energy absorbed by the climate system as well as the infrared radiation emitted to space, and they strongly influence the redistribution of heat throughout the climate system. A change of a few percent in global mean cloud cover or type could either dramatically enhance or counteract the radiative effects of anthropogenic greenhouse gas emissions.

To understand the role of clouds in controlling the Earth's radiative and heat budgets requires knowledge of their distribution, radiative properties, and cloud-radiation feedback mechanisms. For example, ongoing and new research programs that are focused on this area include: NASA's Earth Radiation Budget Experiment; the NASA, NOAA, and NSF International Satellite Cloud Climatology Project (ISCCP) and associated field campaigns; and a broad range of proposed studies and measurements (NASA's Earth Observing System [EOS] and DOE's Atmospheric Radiation Measurements [ARM] program).

(2) *How do the oceans interact with the atmosphere in the storage, transport, and uptake of heat?*

The oceans and atmosphere play a vital role in the transport of energy from the equator to the polar regions. The rate at which the oceans exchange heat with the atmosphere controls the magnitude and timing of the predicted global warming due to greenhouse gases.

The prediction of climate change will require ocean observation systems analogous to the existing atmospheric systems used to predict the weather. Understanding the role of the oceans in exchanging energy with the atmosphere requires knowledge of ocean circulation and air-sea energy fluxes.

Numerous ongoing and new research programs contribute to these areas. *In situ* (NOAA, NSF, and DOI) and remote (NASA scatterometer [Earth Probes] and altimeter [TOPEX]) ocean observation systems will contribute to studies of ocean circulation and the coupling of the ocean and the atmosphere. Interannual climate change (Tropical Ocean-Global Atmosphere [TOGA]: NOAA, NSF, and NASA), and the general circulation of the oceans (World Ocean Circulation Experiment [WOCE]: NSF, NOAA, and NASA) are critical investigations. Other key research includes the NOAA Atlantic Climate Change Project, and the proposed new generation of space-based measurements of ocean altimetry, temperature, and wind stress (NASA EOS).

(3) ***How will changes in climate affect temperature, precipitation, and soil moisture patterns, and the general distribution of water and ice on the land surface?***

Changes in seasonal temperatures, precipitation and soil moisture patterns could have significant ramifications for water resources, agricultural productivity, natural ecosystems, and the exchange of water between oceans and glaciers.

Understanding the distribution of precipitation and the impacts of a changing climate on the distribution of water and ice on land surfaces requires knowledge of the fluxes of energy and water within the Earth system, water resources on the land, and changes in the area and volume of glaciers.

Ongoing and new research programs that will contribute to these areas include: the Global Energy and Water Cycle Experiment (GEWEX: NOAA, NSF, DOI, and NASA); the proposed new generation of space-based measurements of precipitation, winds, water vapor, clouds, and ice extent (NASA Earth Probes and EOS); long-term observational networks of water resources (DOI, NOAA, and DOE); field and modeling studies of the climate sensitivity of watersheds (DOI and USDA); continental-scale hydrologic processes (NSF and DOE), water budgets in managed and manipulated ecosystems (USDA) and in temperate and arctic regions (DOE); and compilation of glacier extent worldwide, but especially in the Arctic and Antarctic, using ground-based and satellite data (NSF, DOI, and NASA).

(4) ***How can the reliability of global- and regional-scale climate predictions be improved?***

Accurate predictions of climate change, whether natural and/or human-induced, are vital for evaluating environmental and socioeconomic impacts. The current generation of climate prediction models is inadequate to confidently predict the magnitude and timing of climate change. This is particularly true at the regional scale.

Improving the reliability of model predictions will require the development of climate diagnostics, model assimilation of climatic data, modeling shorter space and time scales, and an improved parameterization of key Earth system processes.

Ongoing and new research programs that will contribute to these areas include: enhanced climate modeling and diagnostics efforts (NOAA, NASA, NSF, and DOE); mechanistic studies of climatic change through analysis of observations (NOAA and NSF); development of climate modeling data assimilation techniques (NOAA and NSF); a critical review of data needs both for detection of climate change and for climate modeling (DOE); development of regional climate and hydrology models linked to global climate models (EPA and USDA); and the development of the capability to forecast seasonal conditions through coupled ocean-atmosphere modeling and extension of conventional weather prediction techniques (NOAA). Results from a number of process-oriented studies will be utilized to parameterize key interactions in models, including cloud-radiation interactions (NASA, NOAA, NSF ISCCP, and DOE ARM), and land-ocean-cryosphere-atmosphere interactions, including land surface hydrology (NSF, NOAA, DOI, and NASA).

Biogeochemical Dynamics

Table 1 shows that the FY 1991 request for this element is $265.8 million, a $67.1 million or 34 percent increase over the FY 1990 level.

There is compelling scientific evidence that the atmospheric concentrations of several key radiatively and chemically active gases are increasing, due both to natural processes and human activities. The rates of increase of these gases depend not only on their emissions, but also on the fate of these gases, which involves the cycling of carbon and other key nutrients between the ocean, atmosphere, and terrestrial biosphere. Currently, there are significant uncertainties in understanding these processes, thus limiting the ability to quantitatively predict future increases in atmospheric trace gas concentrations. This restricts the formulation of effective policies regarding trace gas emissions.

The FY 1991 research efforts listed below reflect the Program's research priorities (see Figure 1) and involve the following policy-relevant questions:

(1) ***What is the relative importance of the oceans and terrestrial biosphere as sinks for fossil fuel carbon dioxide, and how do they change with time?***

Increasing atmospheric concentrations of carbon dioxide are predicted to contribute to global warming. Presently some portion of the emissions from the combustion of fossil fuels and deforestation stay in the atmosphere, with the remainder being taken up by the oceans and the terrestrial biosphere, but the proportions and responsible processes are not well understood. For a given anthropogenic emission scenario, the prediction of atmospheric growth rates of carbon dioxide depend upon an understanding of this sequestering of emitted carbon dioxide.

To understand the relative importance of the oceans and terrestrial biosphere as sinks for fossil fuel carbon dioxide requires knowledge of biogeochemical and physical processes and the fluxes of carbon and nutrients among and between the atmosphere and land and ocean surfaces.

Numerous ongoing and new research programs contribute to these areas. *In situ* studies of the processes responsible for controlling the concentration, distribution, and cycling of oceanic carbon (NSF, NOAA, and DOE), complemented by remote sensing measurements of ocean productivity, sea surface temperatures, and winds (NASA) contribute towards the Joint Global Ocean Flux Study (JGOFS). *In situ* studies of the sequestering of carbon dioxide and the storage and cycling of carbon and other key nutrients within natural and disturbed terrestrial ecosystems (DOI, NSF, EPA, DOE, and USDA) will be complemented by estimates of standing biomass and the biological productivity of terrestrial ecosystems using satellite imagery (NASA EOS).

(2) ***What are the major sources responsible for the current increases in atmospheric nitrous oxide and methane?***

The well-documented increases in the atmospheric concentrations of methane and nitrous oxide are predicted to contribute to global warming, affect stratospheric ozone, and, in the case of methane, to increase tropospheric ozone. The natural and anthropogenic sources of these gases have been qualitatively explained, but not adequately quantified. Hence, effective emission control strategies cannot be formulated.

Understanding current and future trends in the atmospheric concentrations of methane and nitrous oxide requires knowledge of their emissions from industrial and ecological sources; the processes that control their fluxes between the atmosphere, biosphere, and land and ocean surfaces; the impact of changing environmental conditions upon their fluxes; and their atmospheric distribution and transformations.

Many ongoing and new research programs will contribute to these areas including: studies of the fluxes of methane and nitrous oxide, the processes controlling them, and their response to environmental changes from one or more of the key sources, including natural ecosystems, agricultural systems, managed forests, cattle, biomass burning, and gas hydrates (NASA, NOAA, NSF, EPA, DOI, DOE, and USDA); quantification of the areal extent and environmental and ecological conditions conducive to methane and nitrous oxide emissions from terrestrial ecosystems (NASA EOS); atmospheric distributions and trends of methane and nitrous oxide (NASA and NOAA); and the atmospheric distribution and transformations of species (such as tropospheric ozone, hydroxyl radicals, oxides of nitrogen, carbon monoxide, and non-methane hydrocarbons) that control the distribution and lifetime of methane (NSF, NASA, NOAA, DOE, and EPA).

(3) *What are the implications for stratospheric ozone, globally and in polar regions, of increased concentrations of chlorine and bromine?*

Current scientific understanding indicates that the antarctic ozone hole will seasonally reoccur until the stratospheric chlorine levels decrease by 30 percent from today's level. However, it is not yet possible to quantify, under conditions of enhanced chlorine and bromine concentrations, the impact of the antarctic ozone hole on ozone levels at mid-latitudes in the southern hemisphere or the probability of significant ozone depletion over the Arctic. An improved quantitative understanding of the processes controlling stratospheric ozone, particularly in the polar regions, would allow improved environmental impact assessments to be conducted and improve policy formulation concerning chlorine and bromine containing chemicals, including proposed substitutes.

To understand the response of stratospheric ozone to changes in chlorine and bromine requires knowledge of their fluxes into the stratosphere; the chemical composition and physical structure of the stratosphere; and the coupling between chemical, dynamical, and radiative processes in the stratosphere.

Ongoing and new research programs that will contribute to these areas include: monitoring the atmospheric distribution of the source gases (NOAA and NASA); monitoring the chemical composition and dynamical structure of the stratosphere using a ground-based network of remote sensing, aircraft and balloons, and satellite observations (NASA, NOAA, and NSF); and studying the atmospheric cycling and transformations of compounds that influence the chemistry of the stratosphere (NASA, NOAA, NSF, and EPA).

Ecological Systems and Dynamics

Table 1 shows that the FY 1991 request for this element is $178.6 million, a $88.4 million or 98 percent increase over the FY 1990 level.

Ecological systems are important in global change research for two principal reasons. First, changes in climate, atmospheric composition, and solar radiation can affect the productivity, diversity, and habitat associated with both natural and managed ecosystems. Indeed, much of the policy concern over global change is explicitly linked to such possible ecosystem impacts. Second, photosynthesis, deforestation, and other biospheric processes can affect the chemical composition of the atmosphere, hence contributing to global change. Human influences on ecosystem changes are increasingly a part of current policy debates.

Thus, ecological systems are intrinsically linked to global change through interwoven roles in biogeochemical dynamics, physical climate and the hydrologic cycle, and the actions of humans. However, the scientific uncertainties associated with the composition, distribution, and processes of ecosystems currently slow the formulation of sound, science-based policy options.

The current key questions in these research areas, their relevance to the evolution of public policy of global change, and the associated research of the FY 1991 U.S. Global Change Research Program include the following:

(1) ***What ecological systems are most sensitive to global change, and how can natural change in ecological systems be distinguished from change caused by other factors?***

The diverse climates of the Earth support an equally diverse array of species and ecosystems. Separating the intrinsic natural dynamic changes of ecosystems from those changes induced by human activities is a challenge that has plagued the ecological sciences and the public policy arena for some time.

The highest priority for determining the sensitivity, types, and causes of possible changes in ecosystems is the documentation of past, current, and future variation in ecosystem properties. Several ongoing monitoring programs and proposed research initiatives will address this need with regard to sensitive ecosystems (e.g., boreal forests, grasslands, and arid and high-elevation areas): DOE's research parks, USDA's forests and experiment stations, DOI's parks, wildernesses and other public lands, and NSF's Long-Term Ecological Research Sites. NASA's EOS satellite-based instruments will extend global observations of ecosystem type, state, and spatial extent. Furthermore, EPA, USDA, NSF, DOI, NOAA, and DOE will examine the ecosystem responses (e.g., alpine treeline change in the western U.S., shrub encroachment into rangeland, ecological succession, small-animal ranges and habitats, and marine ecosystems) to carbon dioxide increases, climatic stresses, and other disturbances.

(2) *What are the likely rates of change in ecological systems due to global change, and will natural and managed systems be able to adapt?*

Ecosystem change is controlled by the physiological processes of the individual species, as well as by the environments in which they exist. The photosynthetic response of plants to increased carbon dioxide concentrations is relatively fast and often accompanied by higher biological productivity and drought and salinity resistance. However, the full responses of complex ecosystems, such as forests and rangelands, to changes in the climate system and in the chemical composition of the atmosphere may take decades or longer.

Understanding the ecological response to rates of change and how well ecological systems can adapt to change is clearly linked to quantifying impacts for the formulation of policy options. This will require (i) knowledge of ecological responses to specific forcing agents (e.g., temperature stress, soil moisture, chemical exposure, ocean circulation, and ultraviolet radiation), (ii) research on the interactions between biotic and abiotic processes, and (iii) modeling of interactions, feedbacks, and ecological responses.

The proposed and ongoing research of several agencies will contribute to closing these knowledge gaps. EPA and DOI will develop correlations and models to investigate rates of change in forested and semi-arid ecosystems. USDA, DOE, NSF, and DOI will acquire data on physiological and ecosystem responses in seedling productivity; variation of plant growth due to carbon dioxide, temperature, and ultraviolet exposure; ecosystem changes in high-desert rangeland and coastal regions; successional change of vegetation across climate gradients; and response of managed forests to drought stress. Furthermore, DOE, DOI, USDA, NOAA, and NSF will investigate the responses of particularly sensitive species (e.g., arctic marine mammals, reef corals, commercial fish stock, grasses, grains, and endangered or limited-habitat species) to climatic and other stresses.

(3) *How do ecological systems themselves contribute to processes of global change?*

The biogeochemical and physical feedbacks from living systems strongly influence the fluxes and amounts of methane, nitrous oxide, carbon dioxide, and the reactive trace gases in the atmosphere, as well as albedo and water fluxes. Decisions regarding land-use policies require that these causative interactions be understood and that their feedbacks be represented correctly in global system models.

DOE, EPA, USDA, NSF, and DOI ongoing and new programs will address these needs through projects that determine the influence of soil biology, total biomass, land-cover type, and transpiration on biogenic gas fluxes and evapotranspiration in different vegetation types, and that characterize the interactions between climate, vegetation, and soils in diverse ecosystems.

Earth System History

Table 1 shows that the FY 1991 request for this element is $19.1 million, a $11.4 million or 148 percent increase over the FY 1990 level.

Geological and historical records document the natural variability of the physical environment, climate, and ecosystems from interannual to millennia time scales. These data reveal periods that were significantly colder and warmer than today, as well as past abrupt climate changes and subsequent environmental responses. Understanding this past behavior of the natural system is essential for detecting predicted human-caused perturbations against the background of normal variability and for providing data sets to test climate models. Confidence in model predictions of future change will be increased if the models can reproduce these past climates.

Uncertainties in the predictions of climate models is already a key factor in policy debates, as is whether a greenhouse "signal" can be found in the record of recent decades. In addition, past evidence of the impact of climate changes on ecosystems demonstrates the vulnerability or resilience of these systems to change.

The FY 1991 research efforts listed below reflect the Program's research priorities (see Figure 1) and involve the following policy-relevant questions:

(1) *What are the natural ranges and rates of change in the climate and environmental systems?*

The paleoclimatic record can provide insight into the cause and effect of global changes. The history of atmospheric carbon dioxide and methane along with records of past climates can be reconstructed from ice core samples. Similarly, the temporal covariations in the terrestrial biosphere, the carbon cycle, and climate need to be reconstructed from fossils, ocean sediments, and the geological record.

To address these opportunities and needs, DOI and NSF will focus on developing new paleoclimate methods, reconstruct past abrupt climate transitions and past warm intervals on Earth, and emphasize studies in the sensitive arid (DOI) and polar (NSF and DOI) regions.

(2) ***How rapidly have ecosystems adapted to past abrupt transitions in climate?***

The long-term geologic record contains evidence for a number of minor- to large-scale, rapid changes that have had profound effects on Earth systems and hence offers the opportunity to observe the environmental effects (e.g., extinction and replacement of biota) of a large sudden perturbation.

While the general characteristics and timing of major abrupt changes throughout the geological record are known, the existing studies are generally incomplete and limited in scale and scope. Better understanding of their effects on Earth systems will require the integrating of records on regional to global scales for selected events.

The programs of USDA, DOI, and NSF will contribute studies that emphasize the effects on the biosphere. The ongoing paleoclimate programs of USDA focus on the impacts of fire severity and frequency on the life histories and distributions of biota. New initiatives will study the effects of climate change on arid regions (DOI), and the impact of abrupt climate changes on ecosystems (NSF).

(3) ***Do past warm intervals in Earth history provide appropriate scenarios to test model predictions of future global warming?***

The assessment of the regional predictions of general circulation models will benefit from a comparison to data showing how representative regions responded during past warm periods. Intervals of past warm climates are known, but most of the environmental reconstructions of those times are qualitative and the scope of the variables is not comprehensive, which is a limitation in assessing the reliability of the models.

The Program will focus on determining if regional responses to global warming are similar regardless of local conditions or causes of the warming. This goal will be addressed by existing paleoclimatic research projects, such as the Climate of the Holocene Mapping Project (COHMAP) (NSF and DOE) and the Pliocene Project (DOI), as well as by augmenting existing and supporting new interdisciplinary programs. NOAA will augment its study of integrated paleoclimate investigations and global model assessment for these warm-Earth scenarios.

Human Interactions

Table 1 shows that the FY 1991 request for this element is $15.0 million, a $10.2 million or 212 percent increase over the FY 1990 level.

A comprehensive picture of global change must include the relationship between biological, atmospheric, hydrologic, and terrestrial changes and the human activities that stimulate or mediate them. These relationships include both the cumulative effects of individual or group actions over long periods of time and the less-concentrated, but equally influential, effects of the actions of social and economic institutions. For example, greenhouse gas emissions are due to several social and economic factors, including growth of human population, energy consumption, agricultural and industrial practices, and regulations.

Without an understanding of human behavior and its consequences for the environment, models will be inadequate to explain, or to develop policies to deal with, global change phenomena. The following research efforts reflect the Program's research priorities (see Figure 1) and involve the following policy-relevant questions:

(1) *What kinds of empirical data are needed to measure and understand human interactions in global change?*

The study of human interactions is dependent on having time-series data on a wide variety of human activities and related phenomena, ranging from energy demands to food consumption patterns. The necessary first step is to establish baseline data on environmentally significant human activities that reflect the differing technological, economic, and cultural forces in various societies.

NSF is supporting the collection of baseline data in environmentally critical areas and will establish Long-Term Regional Research Sites. These will support research on methodological problems in creating data bases which span the range of human activities in various regions and societies and will also encompass historical data. DOI will develop data sets for research that addresses the human factors which influence supply and demand of water and land resources. USDA will organize the data necessary for studying the role of human behavior in natural and managed ecosystems, and in the extent and severity of fires. DOE will continue its data collection on fossil fuel utilization and carbon dioxide emissions.

(2) *How and why do human beings and human systems influence physical and biological systems?*

The development of an accurate predictive understanding of human influences on global change (and hence appropriate public policy responses) is dependent upon the availability of data bases that span time and space, characterizing the fundamental processes of change in human systems, and the interactions of these systems with the physical and biological processes. Therefore, a critical early step in understanding human interactions in global change is the support of process studies.

NSF will expand its Human Dimensions of Global Environmental Change Program to put additional emphasis on social processes such as the economic influences in deforestation and the effectiveness of legal and regulatory controls over water resources. NSF's Long-Term Regional Research Sites will be the focus of research on long-term patterns and processes of social, economic, and ecological change. DOI will support the development of methods to estimate: (i) tradeoffs among competing social, environmental, and economic goals, and (ii) the role of human choices on water supplies and in coastal erosion and inundation. USDA's research program will include the effect of fires on rural population distributions.

Solid Earth Processes

Table 1 shows that the FY 1991 request for this element is $80.9 million, a $23.5 million or 41 percent increase over the FY 1990 level.

Many solid Earth processes are directly involved in the life-sustaining elements of the regional and global environment. Melting of glaciers, especially polar ice sheets, would cause sea level to rise; large volcanic eruptions can cause climatic cooling for short periods of time; and methane released from permafrost and gas hydrates in response to climatic warming can change atmospheric composition. An improved understanding of solid Earth processes will allow for more effective long-term planning in those coastal regions most vulnerable to rising sea level and for the protection of human populations most apt to be endangered by volcanic eruptions and other catastrophic solid earth processes.

The FY 1991 research efforts listed below reflect the Program's research priorities (see Figure 1) and involve the following policy-relevant questions:

(1) *How do different coastal regions respond geologically and ecologically to higher sea level, and how can the contributions from changes in climate (e.g., glacier melting and ocean warming) be differentiated from those due to tectonic processes?*

Sea level is predicted to rise as a consequence of global warming, but the absolute magnitude, rate, and timing of the sea level rise are uncertain. Elevated sea level could have serious consequences for coastal environments and human populations, and an improved predictive capability for sea level rise is required for the effective formulation of adaptation or mitigation strategies.

Understanding sea level changes and their consequences requires measurements of the absolute magnitude and rate of sea level rise; differentiation between the contributions of climatic change from those due to movements of the Earth's crust; and prediction of the geological and ecological response of different coastal environments.

Ongoing and new research programs that contribute to these areas include: studies of glaciation and deglaciation during periods of climatic change (NSF and DOI); *in situ* global sea level network (NOAA); satellite ocean altimetry (TOPEX: NASA); the NOAA, NSF, and NASA programs to use the space-based Global Positioning System (GPS), Satellite Laser Ranging (SLR), and Very Long Baseline Interferometry (VLBI) to measure sea level changes; studies of coastal erosion and inundation on the East Coast of the United States (DOI and NASA); Coastal Wetlands Change and Dynamics Program (DOI); and the application of new isotopic methods for dating of landforms, soils, and sediments (NSF).

(2) *What are the magnitude, geographic location, and frequency of volcanic eruptions and their effect on climate?*

Large volcanic eruptions emit gases, ash, and aerosols into the atmosphere that can cause significant short-term perturbations to the Earth's climate by changing the radiative budget. It is essential to quantify climate change induced both by volcanic eruptions and by increased abundances of greenhouse gases.

Understanding the impact of volcanic eruptions on the Earth's climate requires an improved understanding of the magnitude, frequency, and geographic location of subaerial and submarine volcanic events and the nature and amount of emitted material. Hydrothermal venting from the ocean floor is a major source of heat from the Earth's interior, and it influences the global carbon cycle.

Several ongoing and new programs contribute to this research effort including: studies of gas and ash emissions and degassing processes from U.S. volcanoes (DOI); satellite measurements of atmospheric volcanic aerosols and sulfur gases (Total Ozone Mapping Spectrometer, Earth Probes, and EOS: NASA); and studies of the fluxes of energy, gases, fluids, and particulates from submarine eruptions on the mid-ocean ridges (Ridge Interdisciplinary Global Experiment [RIDGE]: NSF, NOAA and DOI).

(3) *How do permafrost regions of the Northern Hemisphere respond to climate warming?*

An accelerated release of methane trapped in arctic permafrost and gas hydrates due to a climatic warming would alter the chemical composition of the atmosphere and further enhance the greenhouse effect. Ongoing and new research will contribute to this area through projects that study the dynamics of permafrost change (NSF) and by assessing whether there is a current climatic warming on a local, regional, or hemispheric scale by monitoring subsurface temperatures in arctic permafrost (DOI).

Solar Influences

Table 1 shows that the FY 1991 request for this element is $13.2 million, a $4.4 million or 50 percent increase over the FY 1990 level.

The sun influences two of the most important current policy-related phenomena: the depletion of ozone by chlorofluorocarbons and climate warming due to greenhouse gases. In both areas, the main scientific problem is one of separating the effects that are due to human influences from changes induced by natural forcing agents, such as the sun.

The FY 1991 research efforts listed below reflect the Program's research priorities (see Figure 1) and involve the following policy-relevant questions:

(1) *What aspects of solar variability are influencing the stratospheric ozone layer?*

Since ozone is generated by the breakup of oxygen by solar UV radiation, observed ozone changes will depend, in part, on solar activity. Thus, the detection of human-caused ozone depletions requires that the solar component of ozone change be properly accounted for. This understanding requires long-term UV observations of adequate precision (±1%) over the solar cycle. The required observations will be provided by instruments on NASA's Upper Atmosphere Research Satellite (UARS) and EOS.

(2) *What impact do other inputs, e.g., particles, have on the upper atmosphere and how are they coupled to other atmospheric regions?*

The physical properties of the upper atmosphere (e.g., temperature, composition, and density) are sensitive to human-influenced gases, such as carbon dioxide and methane, and to solar particles. Changes induced by these agents could be quite substantial and hence could affect satellite orbits and provide insight into potential sun–atmosphere couplings. NSF's Coupled Energetics and Dynamics of Atmospheric Regions (CEDAR) and Geospace Environment Modeling (GEM) programs will begin the establishment of data bases on solar inputs relevant to the global circulation and couplings.

(3) *How does the sun's output vary and what is the impact on terrestrial climate?*

A key factor in establishing the Earth's radiation budget is the total solar radiation reaching the planet. This requires continuous measurements of the total solar radiation with very high long-term stability (0.1%). These observations will be provided by Active Cavity Radiometer Irradiance Monitors (ACRIM) on NASA's UARS and EOS.

Data Management

Table 1 shows that the FY 1991 request for data management is a $129.4 million, a $64.2 million or 98 percent increase over the FY 1990 level.

Data and information management will provide a bridge between global change observations and scientific understanding, and will be a key factor in the success of programs carried out within all seven interdisciplinary science elements. The traditional concepts and present practices of data management are inadequate for global change studies. The interdisciplinary, interagency, and international aspects of these studies, coupled with a long-term view, pose unprecedented challenges to the data management and research communities alike. Consequently, cooperation in seeking new approaches to archiving and management of data is essential.

Data management includes the means and mechanisms to describe, gather, transmit, validate, process, archive, and disseminate data. The initial thrust will be on data base development in the highest priority science elements and strengthening the infrastructure required to process, manage, and improve access to the great variety of ground- and space-based observations.

The key data management questions with policy implications include:

(1) ***How can the data handling and access capabilities be best organized and strengthened?***

Data management systems for global change must be able to accept and archive dissimilar types of data collected from different data collection systems , i.e., both ground- and space-based data by different organizations in different formats and on different media.

Interactions among CES agencies through the Interagency Working Group on Data Management for Global Change and with the science community have begun to facilitate improved access to data and data handling capabilities. A major problem facing scientists attempting to use global change data sets is that it is extremely difficult to find out who has what data and how good the data are. Using existing facilities, NASA, NOAA, NSF, DOE, and DOI will continue to develop and expand a Master Directory for Global Change Data by linking with a common architecture, directories, catalogs, and inventories of data in all global change science elements. Hundreds of global change data sets already have been documented and entered.

Studies have been initiated to develop archives with improved quality control, documentation, and ease of access to satellite data, including formation of the EOS Data and Information System (NASA, NOAA and DOI), and procedures are being developed for better distribution of digital data bases. Access to and assimilation of the DOD environmental data bases are being addressed. Bilateral agreements have been signed between NASA and NOAA and between NASA and

USGS for the development of data systems to manage satellite data. The exchange of satellite information between NASA, NOAA, European Space Agency (ESA), Canada, and Japan has been instituted. NASA and NOAA are gathering relevant foreign data to combine with U.S. data.

(2) ***How can the agencies build the data sets needed to facilitate early results from the Program?***

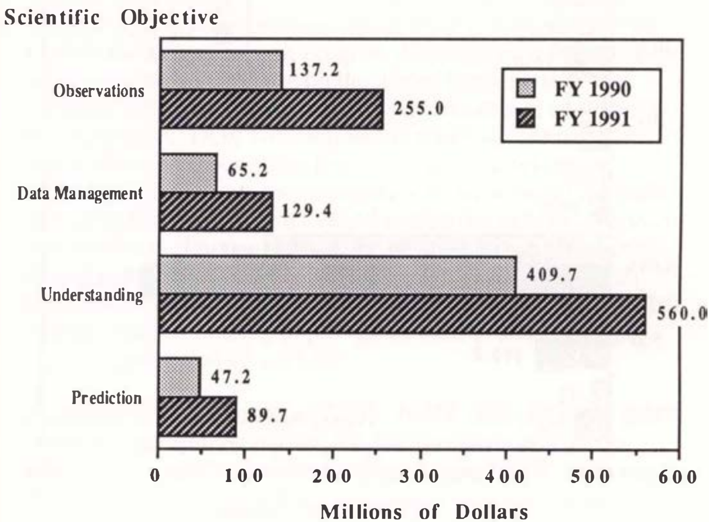
Long-term global measurements must routinely be supported by documentation regarding instrument calibrations, coverage, sampling, data editing, data reduction algorithms, including ancillary data, algorithm validation, assimilation or analysis procedures, and correlative measurements.

Many ongoing and new research programs contribute to the task of developing integrated global-scale satellite and *in situ* data sets that will support model development including the development of data bases in support of: biological responses to climate, abrupt climate change, anthropogenic forces in global change, long-term ecological research, studies of ecosystem stress, land-surface data, fire severity and occurrence, sea surface temperature fields, and regional ecosystem variables that are sensitive to global change. (All CES agencies are involved in one or more of these activities.) DOE will support a critical review of data for climate modeling, and NSF will support a geosystems data base activity that includes the development and quality control of model-generated data sets. On a priority basis, data sets are being extended into the past, both to document global change and to test and validate diagnostic and predictive models. NOAA and NSF data management elements provide resources for the development of historical and paleo data bases. DOE and DOI have similarly focused programs.

Budget by Scientific Objective

Figure 3 shows the FY 1990 enacted and FY 1991 proposed budgets for the U.S. Global Change Research Program by scientific objective: observations, data management, understanding, and prediction. These budgets reflect a balance between each of the scientific objectives, with a strong commitment to data management.

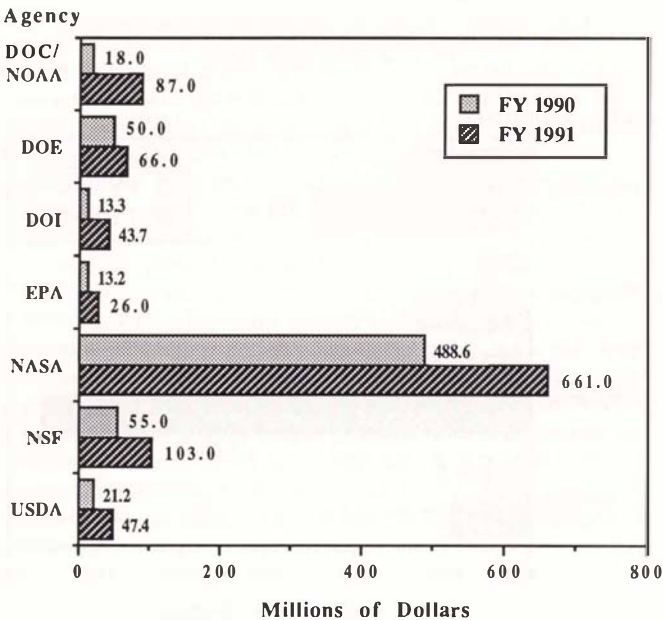
Figure 3
U.S. Global Change Research Program Budget by Scientific Objective



Budget by Agency

Figure 4 shows the FY 199O enacted and FY 1991 proposed budgets for the U.S. Global Change Research Program by agency. The individual agency efforts build upon their respective scientific and technical strengths.

Figure 4
U.S. Global Change Research Program Budget by Agency



National Oceanic and Atmospheric Administration (NOAA). In FY 1991, NOAA has proposed an $87 million Climate and Global Change Program in support of the U.S. Global Change Research Program. This represents a $69 million or 383 percent increase above the FY 1990 level. The FY 1991 NOAA contribution involves enhancements to ongoing efforts in: operational *in situ* and satellite observation programs with an emphasis on oceanic and atmospheric dynamics (including sea level), circulation, and chemistry; focused research on ocean-atmosphere interactions, the global hydrological cycle, the role of oceanic circulation and biogeochemical dynamics in climate change, atmospheric trace gas/climate interactions, and the response of marine resources to climate change and related stresses; and programs to improve climate modeling, prediction, and information management capabilities.

Department of Energy (DOE). In FY 1991, DOE has proposed a $66 million budget for global change research, a $16 million or 32 percent increase above the FY 1990 level. 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, atmosphere, ocean, and ecosystem responses. DOE will augment research on climate modeling; studies of carbon dioxide sources in the atmosphere, oceans, and land; impacts on vegetation and ecosystems; and research efforts to quantitatively describe the radiative balance and the cloud-climate feedback in the atmosphere. New initiatives focus on critical data needs for global change research and the climatic variables that may serve as indicators of global change; and on funding to provide education and training to the next generation of scientists.

Department of the Interior (DOI). In FY 1991, DOI has proposed a $43.7 million budget for global change research, a $30.4 million or 229 percent increase above the FY 1990 level. DOI efforts include studies of: paleoclimates; interaction and sensitivity of hydrologic, ecological, and landscape systems with climate; 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, biological species variation, and land management; and carbon cycle variation studies; as well as archiving and distributing space- and land-based Earth science data.

Environmental Protection Agency (EPA). In FY 1991, EPA has proposed $26 million for global change research, an increase of $12.8 million or 97 percent above the FY 1990 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, wetlands and forests. EPA's research will help provide the process-level understanding and modeling capabilities to predict global change.

National Aeronautics and Space Administration (NASA). In FY 1991, NASA has proposed $661 million for global change research, an increase of $172.4 million or 35 percent above the FY 1990 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.

National Science Foundation (NSF). In FY 1991, NSF has proposed $103 million for global change research, an increase of $48 million or 87 percent above the FY 1990 level. NSF proposes to augment and initiate programs coordinated internationally to observe, understand, and model atmospheric, oceanic, terrestrial, and social processes and their coupled interactions. Studies include ocean circulation, ocean-atmosphere interactions, cloud-radiation interactions, 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 base research and development, and a multi-agency education initiative for global change.

United States Department of Agriculture (USDA). In FY 1991, USDA has proposed $47.4 million for global change research, an increase of $26.2 million or 124 percent above the FY 1990 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 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, and agricultural resources are vital to the health of our Nation. Table 3 shows the FY 1990 enacted and FY 1991 proposed budgets for the U.S. Global Change Research Program by Federal Budget Function. In FY 1991, significant increases above FY 1990 levels are proposed for each budget function. The U.S. Global Change Research Program must be viewed as a single integrated research effort with its success dependent upon cooperation and contributions from each of the individual agency programs.

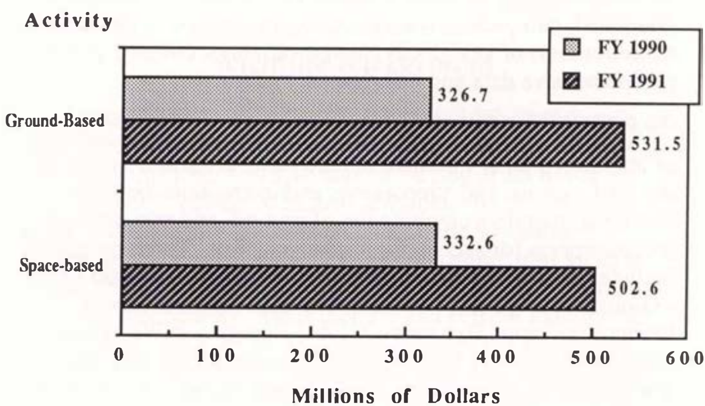
Table 3
FY 1990 - 1991 U.S. Global Change Research Program by Budget Function (Dollars in Millions)

Budget Function	Budget Function Number	1990	1991
TOTAL		659.3	1034.1
General Science, Space and Technology	250	543.6	764.0
NASA		488.6	661.0
NSF		55.0	103.0
Energy (DOE)	270	50.0	66.0
Natural Resources and Environment	300	44.5	156.7
DOI		13.3	43.7
EPA		13.2	26.0
DOC / NOAA		18.0	87.0
Agriculture (USDA)	350	21.2	47.4

Budget by Ground- and Space-Based Research

Figure 5 shows the FY 1990 enacted and FY 1991 proposed budgets for the U.S. Global Change Research Program by space- and ground-based research activities. Maintaining an appropriate balance between ground- and space-based research programs is essential for a successful U.S. Global Change Research Program. *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 to obtain scientific information not attainable from space (e.g., trace gas fluxes). Both types of program need to be strongly supported, and the FY 1991 budget reflects a reasonable balance.

Figure 5
U.S. Global Change Research Program Budget by Ground- and Space-Based Programs



Ground-based: The FY 1991 request for the ground-based program is $531.5 million, a $204.8 million or 63 percent increase over the FY 1990 level. The budgets of NOAA, DOE, DOI, EPA, NASA, NSF, and USDA include support for a broad range of ground-based and modeling research activities. The activities range from small individual investigator research programs to participation in complex international scientific projects. The budgets would initiate multi-agency research thrusts in several critical areas including: the role of the oceans and terrestrial biosphere in trace gas fluxes; the exchange of energy between the oceans and atmosphere; the cycling of water throughout the Earth system; and expanded monitoring of responses to global change, such as sea level.

Space-based: The FY 1991 request for space-based programs is $502.6 million, a $170.0 million or 51 percent increase over the FY 1990 level. The NASA budget includes continued support for TOPEX and UARS, as well as the Earth Probes and EOS initiatives. The TOPEX, UARS, and Earth Probes missions will provide key global measurements, prior to the EOS era that starts in late 1997, including stratospheric composition; surface topography of the global oceans and sea surface wind velocity in order to advance the understanding of ocean circulation; rainfall in the tropics in order to determine the role of tropical precipitation in climate; and ocean color to improve the understanding of ocean productivity. EOS will provide an integrated, comprehensive monitoring program of simultaneous measurements of key global change variables, coupled with a comprehensive data and information system.

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 between them, that require a combination of ground- and space-based measurements for successful implementation. These programs include: World Ocean Circulation Experiment; Tropical Ocean - Global Atmosphere; Global Ocean Flux Studies; Global Ocean Ecosytems Dynamics; Global Energy and Water Cycle Experiment; Global Tropospheric Chemistry Program; International Satellite Cloud Climatology Program; and International Satellite Land Surface Climatology Program.

The Carbon Cycle: An Example of Interdisciplinary Research

Modification of the global carbon cycle by human activities spans both science and policy concerns. This section of the report presents a case study of how the U.S. Global Change Research Program approaches a complex multidisciplinary research area like the carbon cycle.

Policy Needs

Emission of carbon dioxide from the combustion of fossil fuels and changes in land-use practices, and of methane from cattle, rice paddies, permafrost, natural wetlands, gas hydrates, and natural gas production are partly responsible for perturbation of the carbon cycle. Changes in the carbon cycle may affect regional and global climate, the chemistry of the atmosphere, the hydrologic cycle, and the productivity and functioning of ecosystems. Consequently, prudent environmental policy formulation will require a solid scientific understanding of how the carbon cycle varies naturally, how human activities change it, and how it might respond to future changes in environmental conditions.

Scientific Background

Atmospheric carbon dioxide is a radiatively active trace gas with concentrations 25 percent greater now than in the pre-industrial era (prior to 1850) and increasing at about 0.4 percent annually because of human activities. Annual anthropogenic emissions of carbon dioxide are currently about 5.5 billion metric tons from fossil fuel combustion, plus an additional 0.8 to 3.0 billion metric tons from tropical deforestation. Over the past century, fossil fuel use and cement manufacturing released about 200 billion metric tons of carbon into the atmosphere. In the same time period, land-use changes (primarily deforestation) may have released as much as an additional 115 billion metric tons of carbon. However, only 130 billion metric tons of these combined releases remain in the atmosphere. A critical question concerning the global carbon balance is, "What has happened to the remaining carbon dioxide and what will happen to it in the future?"

The natural fluxes of carbon dioxide into and out of the atmosphere from the oceans and terrestrial biosphere are an order of magnitude greater than the anthropogenic fluxes. The oceans, which contain about 50 times more carbon than does the atmosphere, are known to be an important long-term sink for carbon from the atmosphere. In addition, while terrestrial vegetation has always assimilated atmospheric carbon dioxide by photosynthesis, it recently has been suggested that vegetation and soils at northern mid-latitudes may be becoming more effective in sequestering carbon from the atmosphere because of either changes in land management (e.g., reforestation) or because the increasing atmospheric carbon dioxide concentrations may be stimulating plant productivity. These oceanic, terrestrial, biogeochemical, and ecological processes ultimately determine the fate of carbon dioxide from human activities. However, uncertainties in the knowledge of the magnitude of the oceanic and terrestrial sinks limit the accuracy of forecasts of the future fraction of "anthropogenic" carbon dioxide that will remain in the atmosphere.

Atmospheric methane is a radiatively and chemically active trace gas whose concentration is now a factor of two greater than it was in the pre-industrial era and is increasing at about 1 percent annually, presumably because of human activities. The atmospheric abundance of methane is controlled by emissions from oxygen-deficient sources such as natural wetlands, permafrost and gas hydrates, rice cultivation, biomass burning, cattle, natural gas venting, and removal by atmospheric chemical reactions.

Uncertainties in the knowledge of the magnitude of the individual sources and sinks of carbon dioxide and methane severely limit the accuracy of forecasts of their future atmospheric concentrations.

Required Understanding

Biological and physical processes control the uptake and release of carbon by the oceans, and ecosystem dynamics are equally important on land. Economic and human factors dictate the magnitude of fossil fuel emission and the intensity of land disturbance. The task of predicting future abundances of atmospheric carbon dioxide, methane, and other carbon-containing gases requires scientific information, spanning numerous scientific disciplines, including: the exchange of carbon dioxide between the oceans and the atmosphere; the exchange of carbon dioxide and total carbon between the shelves and open oceans, and between the surface waters, deep ocean and sediments; the exchange of gases between terrestrial ecosystems and the atmosphere; the storage and cycling of carbon within terrestrial ecosystems; the extent and ecological state of terrestrial and aquatic ecosystems; atmospheric distributions and transformations of gases; paleocarbon budgets; and the influence of human choices on the carbon cycle.

U. S. Global Change Research Program Approach

After evaluating the policy needs, scientific background, and required understanding, a responsive, multidisciplinary research effort was developed. The box on page 54 gives examples of specific U.S. Global Change Research Program activities related to the carbon cycle. Synthesis and integration of results obtained by investigators working within their numerous disciplines is a critical challenge guiding the U.S. Global Change Research Program. This diversity of research, data collection, and modeling activities is typical of global change research.

Examples of Carbon Cycle Research Activities in the FY 1991 U.S. Global Change Research Program

Climate and Hydrologic Systems

- *General Circulation Models (GCM).* Conduct carbon dioxide scenario experiments in GCMs using coupled atmosphere-ocean models. (DOE, NASA, NSF, and NOAA)

Biogeochemical Dynamics

- *Earth Probes: Satellite Ocean Color Imager and Scatterometer.* Determine ocean productivity and the wind stress at the ocean surface, which will help characterize the carbon dioxide flux across the air/sea interface. (NASA)

- *Ocean Carbon Studies.* Initiate a program of high-precision measurements of carbon dioxide and total carbon, investigate the cycling of carbon in the world's oceans, and determine the air-sea flux of carbon dioxide. (NSF, NOAA, and DOE)

- *Global Carbon Dioxide and Methane Trends.* Monitor the changing abundance of the radiatively active trace species at globally distributed sites. (NOAA, NSF, NASA, and DOE)

- *Terrestrial/Atmospheric Carbon Cycling.* Determine the fluxes of methane and non-methane hydrocarbons from terrestrial ecosystems and the atmospheric processes that establish their lifetime. (NASA, NSF, NOAA, DOE, EPA, and DOI)

Ecological Systems and Dynamics

- *Carbon Cycling in Ecosystems.* Study carbon cycling in terrestrial ecosystems and the processes controlling carbon dioxide fluxes from photosynthesis, respiration, and land-use changes. (DOE, EPA, DOI, USDA, and NSF)

- *Land-Surface Characterization.* Develop data bases for improved vegetation characterization, such as vegetation/land-cover maps, and vegetation greenness indices. (DOI, NOAA, and NASA)

Earth System History

- *Paleo-Atmospheric Carbon Dioxide Abundances.* Carry out ice core studies of carbon dioxide concentrations and other associated variables. (DOE and NSF)

- *Geological History of the Carbon Cycle.* Reconstruct changes in the distribution of carbon isotopes in the Earth's systems. (NSF and DOI)

- *Modeling the Past Carbon Cycle.* Develop models of the long-term partitioning of carbon between the atmosphere, ocean, and terrestrial reservoirs. (DOI)

Human Interactions

- *Carbon Dioxide Emissions.* Develop second-generation carbon dioxide emission models. (DOE)

- *Carbon Dioxide and Standard of Living.* Examine the national differences in fossil fuel consumption and its relation to the standard of living. (NSF)

Solid Earth Processes

- *Volcanic Carbon Dioxide.* Assess long-term volcanic contributions of carbon dioxide to the oceans and atmosphere. (DOI, NSF, and NOAA)

- *Methane Emissions from Permafrost and Methane Hydrates.* Assess the volume and potential release of methane from permafrost and methane hydrates. (DOI and NSF)

Special Issues

The CES has addressed several issues that are important to the success of the U.S. Global Change Research Program. The sections below describe those issues and the approach that CES has taken.

Education

The science of global change is complex and inherently multidisciplinary. While unraveling answers to scientific questions undoubtedly will require new approaches and technology, another important concern is the development of the human resources and scientific talent to conduct multidisciplinary global change research.

To address this need NSF and DOE will initiate human resources programs in FY 1991 that will annually support several hundred postdoctoral appointments, graduate students, and undergraduate students as research participants, as well as several summer institutes on interdisciplinary global change research problems. The NSF program will be managed by representatives from each of the CES agencies. Training opportunities, both in the U.S. and abroad, will include: (i) support at the individual project level, (ii) training centered at major research centers or technology centers, and (iii) opportunities for students to pursue training at institutions of their choice. The DOE program will encourage basic training at universities offering interdisciplinary programs and operational experience in team research at national laboratories and other science and technology centers. In addition, one component of the NASA EOS program is for educational scholarships.

Emerging Disciplines

The U.S. Global Change Research Program presented here should not be viewed as a full exposition of the details of the program in the outyears. The program will evolve as new projects are developed in response to scientific developments and policy needs. Each of the U.S. scientific agencies has programs at various stages of planning, and furthermore, there are major scientific planning activities related to global change within U.S. (Committee on Global Change of the National Academy of Sciences) and international (e.g., the International Geosphere-Biosphere Programme [IGBP] of the International Council of Scientific Unions [ICSU], and the World Climate Research Programme [WCRP] of the World Meteorological Organization [WMO]) scientific communities that have not reached the point of submission to agencies for any formal consideration. Examples include work on paleontology, hydrology, experimental ecology, and human interactions.

International Dimension

The U.S. Global Change Research Program is founded on the premise that international cooperation and coordination are fundamental to the scientific planning and the implementation of the entire Program. Research programs like the IGBP and the WCRP are truly international in scope and in design. The complex scientific agenda and the infrastructure needed to address the programs outlined here require a careful assessment and integration of the Program's components with programs of other governments; intergovernmental bodies (e.g., U.N. bodies such as the IPCC); and international non-governmental science coordinating and facilitating mechanisms (e.g., ICSU).

There is no "international" budget item included in the U.S. Global Change Research Program because it is integral to each project element. A major CES coordinating effort has been initiated with ICSU and the international scientific community, the intergovernmental organizations, and CES-like bodies in other countries. During 1990, it is expected that an integrating infrastructure will begin to evolve; will be endorsed by the various participating agencies, organizations, and institutions; and will involve to some extent the private and industrial sector. Bilateral and multilateral research agreements and programs between the U.S. and other countries are an essential part of this international framework.

Appendix

FY1990-1991 Global Change Research Program by Project

Agency		Project	Program Status
DOC	NOAA	TOGA-Tropical Ocean-Global Atmosphere,. incl. COARE-Coupled Ocean Atmos. Response Expt.	Enhanced
DOC	NOAA	Ocean Dynamics&Circulation: Atlantic Variability	
DOC	NOAA	WOCE-World Ocean Circulation Experiment	
DCO	NOAA	Chemical Tracers & WOCE Hydrography	
DOC	NOAA	Global Hydrological Cycle/GEWEX	
DOC	NOAA	Upper Ocean/Marine Surface Observations	
DOC	NOAA	Stratospheric Monitoring	
DOC	NOAA	Global Sea Level	
DOC	NOAA	Ocean Carbon	
DOC	NOAA	Climate Data Assimilation System	
DOC	NOAA	Long-Term Data Mgmt Planning & Infrastructure	
DOC	NOAA	Climate Modeling & Analytical Centers	
DOC	NOAA	Climate Diagnostics & Database Development	
DOC	NOAA	Paleoclimate Diagnostic Studies	
DOC	NOAA	Marine Sulfur Emissions/Cloud Feedbacks	
DOC	NOAA	Trace Gases/Radiatively Important Trace Species	
DOC	NOAA	Operational Ocean Modeling	New
DOC	NOAA	Long-Term Observing System Planning	
DOC	NOAA	Measurement Technique Development & Testing	
DOC	NOAA	GESDM-Global Environ. Sciences Data Mgmt	
DOC	NOAA	Near-Term Forecasting Improvement	
DOC	NOAA	Marine Ecosystem Response	
DOC	NOAA	Model-Based Fluxes	
DOE	OHER	Core CO_2 Research	Existing
DOE	OHER	Effects	
DOE	OHER	Information/Coordination	
DOE	OHER	Human Interactions	
DOE	OHER	Oceans	
DOE	OHER	Quantitative Links	Enhanced
DOE	OHER	ARM-Atmospheric Radiation Measurements	
DOE	OHER	Data for Climate Modeling/Detection	New
DOE	OHER	Education	
DOI	USGS	Coastal Erosion & Inundation	Existing
DOI	USGS	Permafrost	Enhanced
DOI	USGS	Interaction of Climate & Hydrologic Systems	
DOI	USGS	Land Surface Data System	
DOI	USGS	Paleoclimates Research	
DOI	USGS	Climate Arid Regions	
DOI	USGS	Biogeochemistry of Greenhouse Gases	
DOI	FWS	Coastal Wetland Change & Dynamics	New
DOI	FWS	Monitoring Fish & Wildlife Impacts	
DOI	MMS	Ecosystem Stress	
DOI	MMS	Physical Oceanography	
DOI	NPS	Integrated Studies NPS Ecosystems	

DOI	NPS	Dynamics of Coastal Systems	New
DOI	PBA	MESEEC- Methodologies to Estimate Social, Economic, and Environmental Consequences	
DOI	PBA	TOCSEEG-Tradeoffs between Competing Social, Environmental & Economic Goals	
DOI	BLM	Ecological Change in Environmentally Stressed Ecosystems of the Western & Northern U.S.	
DOI	USGS	Biogeochemical Research	
DOI	USGS	Sensitivity Hydrologic Systems	
DOI	USGS	Land Characterization	
DOI	USGS	Volcano Emissions	
DOI	WBR	Regional Studies	
DOI	WBR	Sensitivity Hydrologic Systems	
EPA	ORD	Emissions Research	Existing
EPA	ORD	Stratospheric Ozone	
EPA	ORD	Ecological effects	Enhanced
EPA	ORD	Regional Climate	
EPA	ORD	Biofeedbacks	
EPA	ORD	Tropospheric Chemistry	
NASA	OSSA	Space- Based	
NASA	OSSA	UARS-Upper Atmosphere Research Satellite	Existing
NASA	OSSA	TOPEX-Ocean Topography Experiment	
NASA	OSSA	Payload & Instrument Development	
NASA	OSSA	Scatterometer	
NASA	OSSA	Operations & Data Analysis	Enhanced
NASA	OSSA	Earth Observing System (EOS) Platform	
NASA	OSSA	EOS-Earth Observing System	New
NASA	OSSA	Earth Probes	
NASA	OSSA	Ground-based	
NASA	OSSA	Solid Earth Science	Existing
NASA	OSSA	Interdisciplinary Research & Analysis	
NASA	OSSA	Suborbital Research Observations	
NASA	OSSA	Model & Data Hydrology/Circ./Physical Climate	Enhanced
NASA	OSSA	Model & Data Solid Earth/Ecological Systems/ Biogeochemical Dynamics	
NASA	OSSA	Hydrologic/Circulation/Physical Climate Processes	
NASA	OSSA	Upper Atmosphere Research Program	
NASA	OSSA	Laser Network	
NASA	OSSA	Ecosystem Dynamics & Biogeochemical Processes	
NSF	GEO	Stratospheric Ozone	Existing
NSF	GEO	Antarctic Ecosystems	
NSF	GEO	TOGA-Tropical Oceans-Global Atmosphere	Enhanced
NSF	GEO	GTCP-Global Tropospheric Chemistry Program	
NSF	BBS	HDGEC-Human Dimensions of Global Environmental Change	
NSF	GEO/BBS	LMER-Land-Margin Ecosystems Research	
NSF	GEO	RIDGE-Ridge Interdisciplinary Global Experiment	
NSF	GEO	Geodynamics	
NSF	GEO	ARCSS-Arctic Systems Science	
NSF	GEO	Geologic Record	
NSF	GEO	CEDAR-Coupling, Energetics, & Dynamics of Atmospheric Regions	

NSF	GEO	GOFS-Global Ocean Flux Study	Enhanced
NSF	GEO	WOCE-World Ocean Circulation Experiment	
NSF	BBS	Bioresponse to Climate	
NSF	GEO	GEWEX-Global Energy&Water Cycle Experiment	
NSF	GEO	GEM-Geospace Environment Modeling	New
NSF	CES/NSF	Education & Training Program	
NSF	GEO	Abrupt Climate Change	
NSF	GEO	GLOBEC-Global Ocean Ecosystems Dynamics	
NSF	GEO/BBS	Geosystems Databases	
NSF	GEO	CHP-Continental Hydrologic Processes	
USDA	ARS	Biological Response to UV-B	Existing
USDA	CSRS	Atmospheric Deposition	
USDA	CSRS	Stratospheric Ozone Depletion	Enhanced
USDA	FS	Water Yield, Erosion & Sedimentation	
USDA	FS	Wildlife/Domestic Species Interactions	
USDA	FS	Aquatic Ecosystems & Fisheries Habitat	
USDA	FS	Fire Severity	
USDA	FS	Energy, Water, Carbon & Nutrient Cycles	
USDA	FS	Microbes, Plant Pathogens & Insects	
USDA	FS	Species Life History	
USDA	ARS	Ecosystem Modeling	New
USDA	ARS	Biogeochemical Fluxes	
USDA	ARS	Ozone Effects	
USDA	CSRS	Methane & Trace Gases	
USDA	SCS	Pedosphere-Paleoecology	
USDA	SCS	Pedosphere-Processes	

Key to Program Status

Existing Program
Enhancement of Existing Program
New Initiative

Agency Acronyms

DOE	OHER	Office of Health & Environmental Research
DOI	FWS	Fish & Wildlife Service
	MMS	Minerals Management Service
	NPS	National Park Service
	PBA	Policy & Budget Administration
	WBR	Bureau of Reclamation
	USGS	U.S. Geological Survey
EPA	ORD	Office of Research & Development
NASA	OSSA	Office of Space Science & Applications
NSF	GEO	Geosciences Directorate
	BBS	Biological, Behavioral & Social Sciences Directorate
USDA	ARS	Agriculture Research Service
	CSRS	Cooperative State Research Service
	FS	Forest Service
	SCS	Soil Conservation Service

Global phytoplankton concentrations change seasonally. This three-month composite of phytoplankton concentrations for April—June in 1979 and 1980 shows the "blooming" of phytoplankton over the entire North Atlantic with the advent of northern hemisphere spring. Phytoplankton pigment concentrations range from red (most concentrated) to purple (least concentrated). These measurements were made by the Coastal Zone Color Scanner (CZCS), a radiometer that operated on NASA's Nimbus 7 satellite from 1978 to 1986.

The U.S. Global Change Research Program