Global Change Research and NASA's Earth Observing System

November 1993

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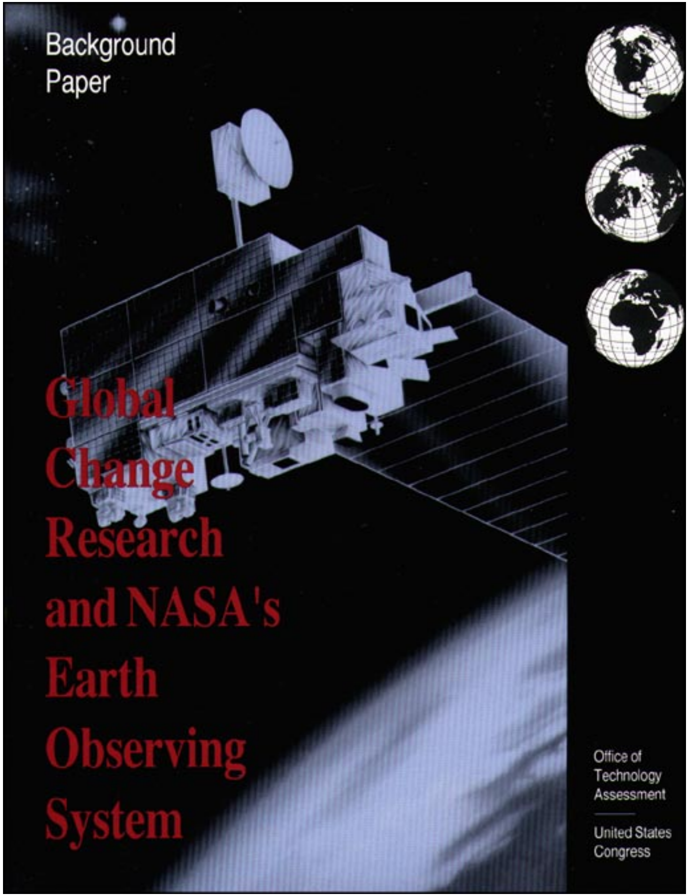

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Foreword

The United States is spending billions of dollars in a multiyear Global Change Research Program (the USGCRP) to monitor, understand, and ultimately predict the nature of global changes and the mechanisms that cause them. This background report examines the direction and scope of USGCRP and its most expensive component, NASA’s Earth Observing System (EOS) of satellites. In particular, it examines how well USGCRP and EOS are fulfilling their scientific objectives, whether some program elements are missing or need to be strengthened, and whether the program is meeting the needs of policymakers.

The background paper responds to issues raised in two related OTA reports: *The Future of Remote Sensing From Space: Civilian Satellite Systems and Applications,* undertaken by OTA’s International Security and Commerce Program, and *Preparingfor an Uncertain Climate,* recently released by OTA’s Oceans and Environment Program. Requesters for these assessments are the House Committee on Science, Space, and Technology; the Senate Committees on Commerce, Science, and Transportation; and on Environment and Public Works; the House and Senate Appropriations Subcommittees on Veterans Affairs, Housing and Urban Development, and Independent Agencies; and the House Permanent Select Committee on Intelligence.

This background paper describes a number of suggestions to improve the value of the USGCRP to both scientists and policymakers. For example, it observes that the USGCRP is focused narrowly on climate change. As a result, USGCRP may not be able to provide decisionmakers and natural resource managers with the information they will need to respond to other aspects of global change, The background paper also explicates the continuing debate over whether the sensors and satellites planned by USGCRP: 1) will be able to acquire data in sufficient detail to elucidate the mechanisms responsible for global change; 2) are appropriate for long-term monitoring of key indices of global change. Decades of continuous calibrated global observations from both space and strategically located sites on the Earth’s land and oceans will be required to document climate and ecosystem changes and for differentiating natural variability from changes induced by human activities.

In undertaking this effort, OTA sought the contributions of a wide spectrum of individuals and organizations, and several Federal agencies. OTA also drew heavily on discussions at a 2-day workshop that assembled a small group of leading global change researchers and current and former officials of the USGCRP and EOS programs. OTA gratefully acknowledges their contributions; however, as with all OTA reports, the contents are the sole responsibility of the Office of Technology Assessment.

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NOTE: 07A appreciates and is grateful for the valuble assistance and thoughtful critiques provided by the workshop participants. The participants do not, however, nessarily approve, disapprove, or endorse this report. OTA assumesfull responsibility for the report and the accuracy of its contents.

Contents

Summary and Findings 1

Over the past several decades, scientists and policymakers have come to recognize that human activity can alter the global environment significantly. Concerns have focused particularly on global warming, the anticipated result from emissions of greenhouse gases such as carbon dioxide, and on depletion of the stratospheric ozone layer, which is linked to anthropogenic emissions of chlorofluorocarbons (CFCS) and other chlorine-containing, molecular species. As part of an international effort to evaluate such risks, the U.S. Government established a comprehensive interagency research effort in January 1989 to ''monitor, understand, and ultimately predict,'' the nature of global changes and the mechanisms that cause them.[1] This effort, designated as the U.S. Global Change Research Program (USGCRP), consists of both pre-existing and new programs. Since its inception, cumulative government expenditures for US GCRP-related programs have totaled some $3.7 billion.

The largest single element of USGCRP research is the National Aeronautics and Space Administration's (NASA'S) Mission to Planet Earth (MTPE), a program that uses space and ground-based instruments to study and understand global

[1] Committee on Earth Sciences (CES), *Our Changing Planet: The FY 2990 Research Plan* (Washington DC: Committee on Earth Sciences, Executive Office of the President, 1989). The CES and its successor, the Committee on Earth and Environmental Sciences (CEES), were formed by the President's Office of Science and Technology Policy.

change. NASA's Earth Observing System (EOS),[2] which consists of a series of polar-orbiting and low-inclination satellites for global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans, is the central component of the MTPE (see ch. 3).

OTA's examination of the direction and scope of U.S. global change programs was prompted by issues that include:[3]

- public expressions of concern by several knowledgeable scientists that the science objectives of USGCRP might not be met,
- sharp reductions in NASA's long term funding plans for EOS and the curtailment of other complementary components and initiatives within the USGCRP, and
- concerns that the U.S. Global Change Research Program is focused too narrowly on scientific understanding of climate change.

Years of effort and billions of dollars could be misdirected if global change research programs do not focus on the right scientific and policy questions, or if planned research programs, instruments, and instrument platforms are inappropriate to address these questions.

As part of its assessment, OTA organized a 2-day workshop that examined how well USGCRP and its EOS component were fulfilling their scientific objectives, whether some program elements were missing or needed to be strengthened, and whether the programs were meeting the needs of policymakers. Workshop participants were asked to evaluate global change research programs with the spectific objective of improving the organization and execution of the USGCRP—they were not asked to debate the relative merits of funding global change research versus competing priorities.

Workshop discussions focused primarily on:

- areas of imbalance in each of the programs,
- how USGCRP-sponsored scientific research programs might better serve the needs of policymakers, and
- the organization and funding of both programs.

The workshop, held at OTA on February 25-26, 1993, assembled a small group of leading global-change researchers and current and former officials of the USGCRP and EOS programs. This background paper draws on the discussions of that workshop and on two previous OTA reports.[4] In preparing the background paper, OTA also gathered information from articles, reports, and private discussions with individuals representing a wide variety of scientific and policy viewpoints. This paper notes, where possible, areas of substantial agreement among workshop participants; however, the conclusions reached in this paper should be attributed to OTA unless stated otherwise.

In structuring the USGCRP, officials made difficult compromises to match existing and planned agency programs to authorized and appropriated funding. Workshop participants were not asked to pass judgment on the wisdom of specific programmatic decisions, for example, individual instrument selections for EOS satellites. Instead, starting with the premise that a

[2] U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing from Space: Civilian Satellite Systems and Applications*, OTA-ISC-558 (Washington, DC: U.S. Government Printing Office, July 1993), ch. 5 and apps. A and B. For a chronology of program restructuring, and a complete description of EOS technology see Ghassem Asrar and David Jon Dokken, editors, *EOS Reference Handbook* (Washington DC: Earth Science Support OffIce-National Aeronautics and Space Administration, March 1993),

[3] Impetus for this background paper also came from two related OTA assessments: 'Civilian Earth Observation Systems, ' an assessment undertaken by OTA's International Security and Commerce Program, and 'Preparing for an Uncertain Climate,' an assessment within OTA's Oceans and Environment Program.

[4] U.S. Congress, Office of Technology Assessment *The Future of Remote Sensing from Space*, op. cit. footnote 2; U.S. Congress, Office of Technoloyg Assessment, *Preparing for an Uncertain Climate, OTA-O-563* (Washington, DC: U.S. Government Printing Office, November 1993).

strengthened global change research program was desirable, OTA sought a broad look at the USGCRP to determine whether it would be possible to improve existing programs. Appendix A of this background paper presents OTA's workshop premise and questions to participants.

EOS AND THE USGCRP: THE CURRENT PROGRAM

1. The research now funded through the USGCRP will help answer some of the most important questions of global change. Nevertheless, the USGCRP and its largest component, the Earth Observing System, could be strengthened substantially by redirecting existing funding and by adding some relatively modest funding for several critical areas. Suggestions for improvement include:

l.a *Increasing funding for focused, process-oriented*[5] *research* to facilitate the detailed measurements essential to answering some of the key questions that underlie the USGCRP'S research agenda (box l-A). Instruments flown on aircraft and balloons, and instruments placed at strategically located sites on land, and on and beneath the oceans, facilitate unique andcomplementary measurements to those planned for satellites. They are also better able to meet particular measurement needs on a shorter term basis than satellite systems.[6]

I.b *Funding some comparatively inexpensive correlative (ground-truth) measurements via airborne or ground-based remote sensing methods to support satellite systems and to monitor changes over time.* According to OTA workshop participants, these critical measurements have lacked funding and professional attention. Workshop participants agreed that such measurements would greatly enhance the scientific value of measurements by the planned EOS system of satellites. Costs for such efforts could range up to a few tens of millions of dollars each year.[7]

1.c *Increasing funding for the development and procurement of Unpiloted Air Vehicles (UAVS) and lightweight instruments specifically designed to gather data in currently inaccessible regions of the atmosphere (see* ch. 3).

l.d *Making greater use of smaller satellites. In* rescoping EOS to accommodate a substantially reduced funding program, program officials deleted instruments necessary to maintain continuity in the measurement of several important climatological variables. Small satellites could help fill these gaps while also providing relatively low-cost test beds for advanced technology.[8]

l.e *Adding a component speciafically tailored to long-term monitoring of key indices of global change.* The Earth undergoes major processes of change that are reckoned in

[5] Process studies will typically be designed to elucidate the details of a particular mechanism of some geophysical, chemical, or biological interaction for example, ozone depletion. They should be contrasted with the regular collection of data on climatological and other variables, which is frequently referred to as monitoring.

[6] They are also needed for longer term measurements. This can be seen, for example, in the ongoing aircraft measurements that seek to understand the phenomena responsible for ozone depletion through high resolution in-situ measurements.

[7] Programs to verify and calibrate Earth observation satellites (and to provide coverage when satellites are not operating) have been funded at lower levels than originally planned. One workshop participant attributes this to the tendency to treat correlative measurements as merely a secondary adjunct to the satellite measurements. In fact, correlative measurements: 1) are essential to the credibility of satellite measurements; 2) have proved unexpectedly difficult to perform; 3) are serious research endeavors in themselves.

[8] However, small satelites have significant weight and volume constraints that limit applications. For example, using near-term technology, small satellites would be unable to acquire high spatial resolution data over wide swaths. For further discussion of small satellites and advanced technology sensors see *The Future of Remote Sensing from Space,* op. cit., footnote 2, pp. 16-17; 128-135.

Box I-A–Understanding the Mechanisms of Global Change

U.S. Global Change Research Program (USGCRP) officials believe their programs will address the most pressing scientific questions related to global change. However, participants at the OTA workshop reflected divisions within the scientific community when they considered the question of whether USGCRP and its largest component, EOS, had an appropriate strategy to expose the mechanisms that govern global change phenomena. Much of this dispute centers on the balance in USGCRP between satellite-based measurements and ground-and airborne-based measurements.

The overarching questions related to global change are obvious. In climate, for example, they include whether the average global climate is changing; if it is, what are its causes; and what would be the effect of exercising different policy options. However, to address these questions requires answers to a series of much more detailed questions, many of which cannot be answered using only satellite-based instrumentation. For example, water vapor and clouds are the dominant regulators of the radiative heating of the planet. However, continuous in-situ observations from the surface to some 25 km altitude are required to answer the following questions:

1. How do clouds and water vapor affect the amount and distribution of solar energy that is available to the planet;
2. How **do clouds and water vapor regulate the amount of thermal** energy that leaves the planet; and
3. How might this balance might be affected in response to *climate changes,* for example, a future atmosphere that contains larger concentrations of greenhouse gases.

Understanding the mechanisms responsible for the onset of ozone depletion also requires in-situ and ground-based studies. Average ozone concentrations over wide areas can be monitored by satellite, but an understanding of the interacting processes governing the formation of the Antarctic ozone 'hole' has been possible only by analyzing in-situ data gathered by high-altitude aircraft and balloons. In fact, scientists were surprised to learn that extremely high resolution simultaneous measurements of several species of gases were required to understand the chemical and physical mechanisms responsible fort deformation of the Antarctic ozone hole. This knowledge has direct bearing on a question of keen interest to U.S. decision makers-where and how fast ozone loss might occur over northern latitudes.

scales of decades to millennia.[9] Decades of continuous calibrated global observations from space and at strategically located sites on the Earth's land and oceans will be required to document climate and ecosystem changes and for differentiating natural variability from human-induced changes.

Determining an appropriate architecture for the space-based segment of a long-term monitoring system has proved especially controversial. As planned, EOS will last only 15 years; however, program officials expect some research instruments may eventually be transferred to the National Oceanic and Atmospheric Adstration (NOAA) for routine data collection (the NOAA "operational" satellite program) over a longer term. NOAA would require augmentation of its budget to incorporate the costs of better instrument calibration and other features necessary to make them suitable to document global change. Some participants expressed doubt that future administrations or Congresses would provide the necessary additional funding; they advocated the design and launch of small

[9] *Our Changing Planet:* op. cit., footnote 1.

A balanced program to study and monitor global change would include long-term local, regional, and global observations, process studies, theoretical modeling, and assessments. iVWrkshop participants agreed that a carefully balanced program of in-situ and satellite observations is necessary to address the fundamental scientific issues that underlie the USGCRP research agenda.

Much of the controversy over whether USGCRP is "scientifically sound" is centered on the plans for the Earth Observation System program. Embedded in this dispute is the issue of whether large and comparatively expensive polar-orbiting satellites are suitable both for studying Earth processes and for long-term monitoring of climatologicai and other variables related to global change. Some participants believe that the high cost and scientific imitations of the present EOS program argue for comprehensive reviews followed by program restructurings. Others believe the program has already undergone sufficient review. Related to this is the argument that the best is the enemy of the good, and timely execution of research plans will yield greater scientific return than that which might follow a further restructuring.

EOS officials reject the criticism that planned sateillte-based instruments have not been designed to answer specific key questions. Furthermore, they argue that the program cannot tolerate substantive restructurin~t least in the near term. However, as noted in the text, a successful long-term program will be possible only if mechanisms are in place to facilitate mid-course corrections in project planning to account for shifting scientific priorities, changes in technology, and scientific surprises. Workshop proposals to strengthen global change programs included redirecting some funds for "ground-truth" and correlative measurements and for augmenting such potentially cost-effective programs as unpiloted air vehicles (see ch. 3).

SOURCE: Office of Technology Assessment, 1993.

satellites specifcally tailored for environmental monitoring.[10] Chapter 3 summaries one such proposal for a small satellite to measure global climate radiative "forcings and feedbacks."[11]

Other elements in the debate over whether EOS should be restructured include:

- concerns that the funding for satellites planned to overlap and succeed the frost series of EOS polar orbiters will not materialze;
- questions about whether NASA is the appropriate agency to undertake long-term monitoring of global change; and
- interest in possible "convergence" of satellite systems designed to meet the needs of the USGCRP, NOAA, and the Department of Defense.[12]

Workshop participants differed on whether or not funds for augmenting the USGCRP (and its EOS component) should come from redirecting already tight budgets. In particular, this dispute separated those participants who believed NASA could achieve its scientific objectives for EOS with the planned system and those who believed the program would benefit from an independent, comprehensive review, followed by restructuring.

10 Small satellites are already part of the NASA'S Mission to Planet Earth. As part of its Earth Probes program NASA is funding small satellites that are precursors or adjuncts to the EOS missions. These include the Total Ozone Mapping Spectrometer (TOMS), the Sea-viewing, Wide-Field-of-View Sensor (Sea-WiFS), which will be launched on Orbital Science Corp. 's SeaStar satellite, and the Tropical Rainfall Measuring Mission (TRMM).

11 Radiative forcings are changes imposed on the planetary energy balance; radiative feedbacks are changes induced by climate change (see box 3-D).

12 See app. B and app. C of *The Future of Remote Sensing from Space*, op. cit., footnote 2.

Both sides in this debate agreed that substantive restructuring of EOS could not be accomplished without, in effect, designing a new global change research program. EOS has already been pared to a system ''with a minimum set of instruments to pursue the focused objective of global climate change, "[13] According to NASA, ''undoubtedly, further budget cuts would require wholesale elimination of instruments, thus information critical to understanding global climate change [would be lost]. [14] Attempting to design a restructured global change research program—either to refocus the program scientifically, or to accommodate possible future funding shortfalls —was beyond the scope of the OTA workshop.

USGCRP: FUTURE DIRECTIONS

2. As currently structured, USGCRP will not be able to provide decisionmakers and natural resource managers with the information they will need to respond to global change. The USGCRP is overwhelmingly a physical sciences program aimed at observing, understanding, and predicting climate change. However, global change encompasses possible alterations in the Earth's environment other than climate. If the USGCRP is to become a comprehensive program to study the causes and potential responses of global change, it would benefit from the following suggested improvements:
   - 2.a *Broadening the scientific scope of USGCRP to include aspects of global environmental change other than climate change.* Several workshop participants believe that determining the extent, causes, and regional consequences of global climate change, the highest priorities in USGCRP, are not the most pressing issues in global change research. Issues cited as more pressing include the consequences of loss of ecosystems and biodiversity, increases in population, and changes in land-use. [15] A broadened program would include research on ozone depletion, changes in biodiversity and forest distributions, desertification, and changes in ocean and coastal ecosystems.
   - 2.b *Strengthening research efforts on the impacts of climate change on society and the natural world.* This would include research on adaptation to, and mitigation of, climate change. In particular, USGCRP should strengthen research on potential changes in ecosystems, such as species composition, and the effects of climate change on agriculture, energy use, and other economic activities. Research on important ecological changes have been either ignored by USGCRP or addressed only to the extent that they interact with the climate system.
   - 2.C *Defining and giving greater emphasis to the newly established assessment element in USGCRP.* Maintaining the policy relevance of scientific research to the decision-making process over the long term requires effective methods to integrate and communicate research results from diverse disciplines (box l-B). USGCRP integrated assessments can be used to identify key societal concerns related to global change, integrate research results from multiple disciplines, analyze potential responses,

[13] *EOS Reference Handbook*, Op. Cit., footnote 2, p. 12.

[14] Ibid.

[15] Biodiversity was cited as a critical issue because, according to one participant, "we are in the middle of an extinction that is unsurpassed in the geological record that is clearly due to human influence. ' Population changes and land-use changes are of critical importance to densely settled developing nations.

and assist in the definition and periodic review of scientific research programs.[16]

Scientific research should inform the policy process by bringing to the attention of policymakers the research results that could affect political decision making. Past research efforts, such as the National Acid Precipitation Assessment Program (NAPAP), have suffered because policymakers have not always understood the limitations of scientific research and scientists have not always understood the needs and time-scales for decisions of the policy making community (app. B). The OTA workshop concluded that programs within the USGCRP would benefit if 1) policymakers had a better understanding of what they were buying with government research dollars; and 2) policymakers had better mechanisms for measuring program progress.[17]

USGCRP: STRENGTHENING THE PROGRAM

Fulfilling the USGCRP'S objectives will require long-term institutional and financial commitments, a greater commitment by non-NASA participating government agencies, and improved mechanisms for program review and coordination. A global environmental monitoring program will, by necessity, also require a broad-based international effort.

3. A successful global change research program—like any long-term research effort—must allow for redirection, substitution, or termination of program elements in light of new discoveries, advances in technology, and changing needs of policy makers.

Workshop participants had several suggestions for facilitating redirection and for improving the management of global change research. These included undertaking periodic, comprehensive reviews of the scientificc foundations of USGCRP and EOS programs under the auspices of an independent scientific body such as the National Academy of Sciences (NAS). These reviews should:

- be completed in 6 to 9 months (faster than the typical NAS study),[18]
- strive to include independent representatives from the science community and other relevant experts,
- not be so frequent as to delay progress, and
- be chartered to recommend both the elimination of ineffective programs and the creation of new programs.

Workshop participants were adamant that the review process should be sheltered from political pressures to redirect programs according to the ''crisis of the day.'

4. The U.S. Global Change Research Program has suffered from fragmentation of research efforts.

The USGCRP could benefit from closer connections with its Research Program on the Economics of Global Change. This program seeks to evaluate the likely magnitude of societal costs and benefits of global change, and evaluates options designed to limit adverse economic and social consequences. Similarly, the USGCRP

16 However, several workshop participants strongly cautioned against too much emphasis on ''top-down'' management of basic scientific research. As one participant explained, ''Basic science research can be guided by the assessment component only in part. The acceptance of the unpredictability of important parts of scientific progress is fundamental to optimal progress.'

17 One of the more recent attempts to bridge the gap between science research and the policy process in USGCRP was to introduce scientific "milestones' or goals that can be easily identified by policymakers to help keep track of progress and program direction, However, this approach has had only limited success. According to one workshop participant, "the [scientific] community hasn't really bought off on those milestones . . . unless the community . . . feel[s] a sense of ownership of that list, it is not only worthless, it is counter productive. "

18 Unless it is part of an ongoing effort, a typical NAS study generally requires some 18 months.

Box l-B-Science, Public Policy, and Integrated Assessments

A central objective of the U.S. Global Change Research Program (USGCRP) is to gain a predictive understanding of global change phenomena A key assumption is that policymakers will be able to use this knowledge to mitigate global change and /or craft suitable adaptive responses.However, scientific understanding of global change will not be sufficient for policy purposes if it isn't also coupled with a mechanism to communicate results in an understandable manner. Even then, policy prescriptions will differ because of differences in veiwpoint that enter as part of the political process.[1]

Policymakers and scientists have different educational and professional backgrounds. Integrated assessments of global change area mechanism for synthesizing all of the scientific, economic, and social aspects of a particular issue and presenting findings in "policy-relevant" language. Although assessments were not included in the original USGCRP program, they are included in a rudimentary form in the fiscal year (FY) 1994 budget. The primary function of the Assessment working group is to:

> .,. document the state of scientific knowledge and address the implications of the science of global change for national and international poilcy-making activities **over a broad spectrum of globai and reginal environmental issues.**[2]

The group will also help coordinate the scientific assessments of global change with related assessments on environmental impacts, technologies for adaptation and mitigation, risk assessment and policy-response strategies.[3]

Although the FY 1994 budget proposal reflects these changes, it is unclear how much money agencies will allocate for assessment and how the assessments will be structured. The Fy 1994 budget does not show Assessment separately but, instead, embeds it within the other three USGCRPactivity streams-docu mentation, process research, and integrated modeling and prediction (see ch. 2). Comprehensive assessments cannot be carried out withhout expanding the ecological and socio-economic aspects of the program and incorporating impacts research. The FY 1994 budget does not reflect any significant expansion in these areas.

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1 Ronald D. Brunner and William Ascher, "Science and Social Responsibility," Social Sciences, vol. 25, No. 4, 1992, pp. 295-331. This view is recognized by the National Academy of Sciences, which has noted, "NO matter how good the science, environmental problems cannot be solved without integrating the science with environmental policy." National Research Council, Research to Protect, Restore, and Manage the Environment (Washington, DC: National Academy Press, 1993).

2 Committee on Earth and Environmental Sciences (CEES), Our Changing Planet: The FY 1994 U.S. Global Change Research Program (Washington, DC: CEES, 1993),

3 Corell, R.W., Committee on Earth and Environmental Sciences, Subcommittee on Global Change Research, and Geosciences, National Science Foundation, testimony before the House Subcommittee on Space, Committee on Science, Space, and Technology, Mar, 30, 1993,

could benefit from closer coordination with ongoing Federal efforts to develop "environmental technologies' appropriate to global change mitigation and adaptation strategies. Currently, such research is not a formal element of the USGCRP (figure l-l), nor is ecosystem-wide research on natural resources and impacts of climate change.[19] With these elements fully incorporated, USGCRP would be better able to address the full spectrum of issues associated with global change.

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19 See U.S. Congress, Office of Technology Assessment, *Preparing for an Uncertain Climate*, Op. Cit., footnote 4, for a discussion Of these issues.

Nonetheless, the Clinton administration has expressed interest in significantly broadening the USGCRP to include studies of environmental and socio-economic impacts and of mitigation and adaptation strategies.[4] If t his research materializes, it could be integrated with research on Earth systems processes to conduct integrated assessments. The expanded program is expected to be reflected in the IV 1995 USGCRP budget.

Integrated assessments could help determine the importance of the problems presented by global change relative toot her policy problems, outline alternative policies to respond to global change, and explain the benef its and drawbacks of various responses and implementation strategies. Just as important, integrated assessments may help guide research by identifying key assumptions, uncertainties, gaps, and areas of agreement. However, integrated assessments have important limits. In particular, their predictive power is limited because they must implicitly or explicitly include assumptions about the political setting, which can be upset by dramatic and unpredictable changes in the structure of economic or political systems.

The accuracy of models of future energy consumption that were generated in the late 1970s provides an instructive lesson. The predictions of these models about per capita energy consumption, and the policy recommendations that followed from them, were dramatically undercut by the 1979 Arab oil embargo, which encouraged consumers to cut their oil consumption.[5] In addition, because energy models were necessarily comprehensive on national or global scales, they obscured regional differences that were critical to political debates in Congress.

The global change research community faces the challenge of devising assessments that minimize disruption of ongoing programs while still allowing for redirection of program elements in light of new discoveries, advances in technology, and changing long-term needs of policy makers.

4 J.H. Gibbons, Assistant to the President for Science and Technology, memorandum to Frederick M. Bernthal, Acting Director, National Science Foundation, July 8, 1993.

5 See Brunner and Ascher, Op. cit.

SOURCE: Office of Technology Assessment, 1993.

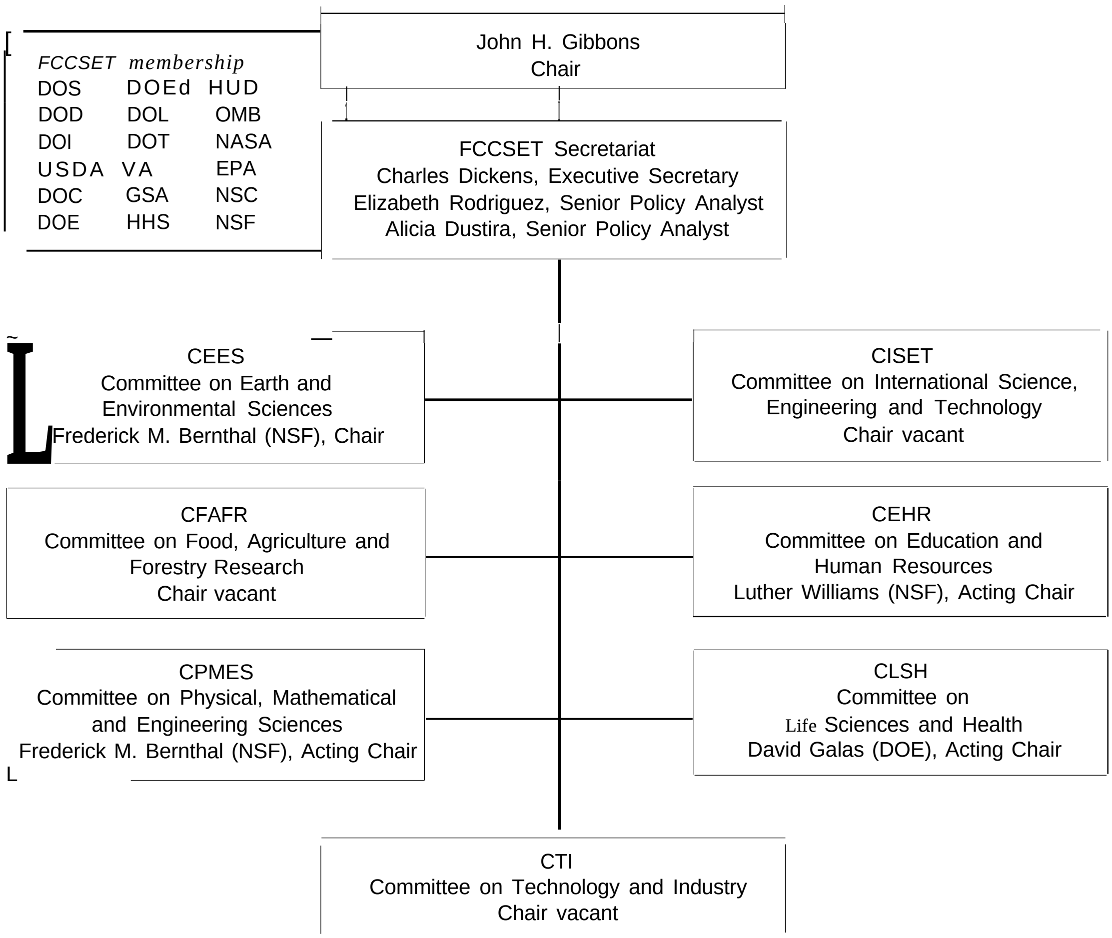
5. The current authorization and appropriations process guarantees that L'SGCRP, a multidiscipline, multiagency program to understand the Earth as a system, will be examined by Congress largely in disaggregate pieces. This affects the effectiveness of congressional oversight of the Program. It also results in agency shares of USGCRP remaining approximately fixed from year to year.

Jurisdictional barriers between authorizing committees and multiple appropriations from separate subcommittees limit Congress' ability to view the USGCRP as a whole. According to workshop participants, this capability is one of the strengths of the executive branch's FCCSET (Federal Coordinating Council for Science, Education, and Technology) process.

The congressional budget process typically only allows small percentage changes in agency budgets from year to year. As a result, funds for new global change research may be easier to obtain through a small percentage increase in NASA's USGCRP budget ($921 million in fiscal year (FY) 1993) than, for example, NOAA's USGCRP budget ($67 million in FY 1993) or DO1'S USGCRP budget ($37.7 million in FY 1993). The unintended effect of this budget process is that NASA plays a de facto leading role in both space and surface-based global change research programs,

6. Restoring the authority of the Committee on Earth and Environmental Science (CEES) of the FCCSET to fence off agency budgets might improve the balance of resource allocations among agencies and between

Figure 1-1A—Organizational Chart for the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET)



NOTE: for definition of terms, see figure 1-B, next page.

(Continueo)

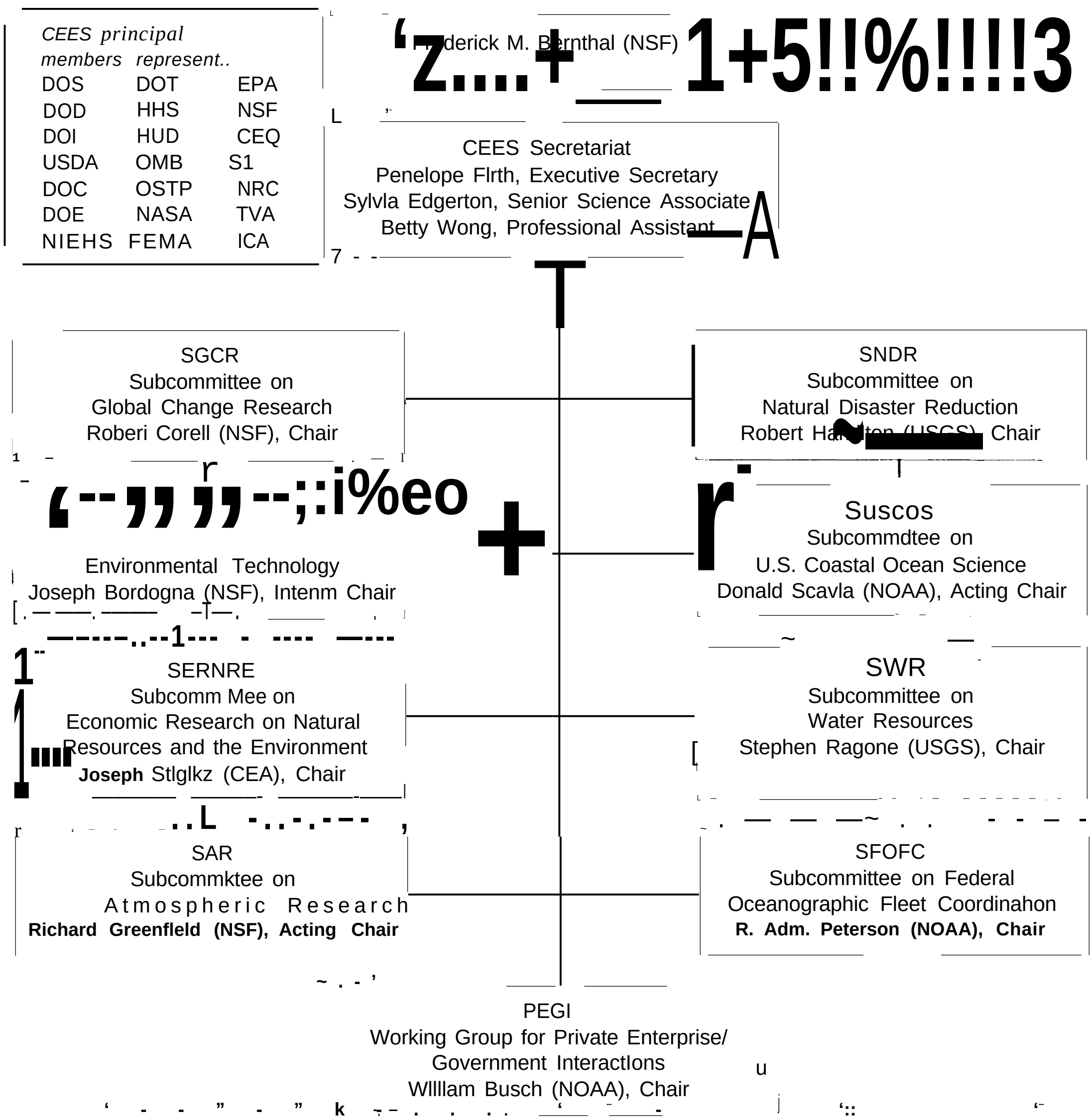
satellite and non-satellite program elements (box 1-C and ch. 3).[20]

During the first years of the program, USGCRP required agencies to ''fence off,' or commit their global change research budget requests to the Program. Agencies could not later reprogram this money if overall funding was less than expected. Several participants at the OTA workshop recommended the reinstatement of such a system.

7. NASA has been able to attract large amounts of funding for its Earth Observing System; however, potentially cost effective, but less glamorous programs outside NASA have languished.

20 In September 1993, President Clinton announced the formation of a new science policy coordinating body, the "National Science and Technology Council." It is unclear what effect of the Council on the FCCSET process for funding USGCRP will be.

Figure I-l B—Organizational Chart for the Committee on Earth and Environmental Sciences (CEES)



NOTE: DOS= Department of State; DOD= Department of Defense; DOI=Department of the Interior; USDA=U.S. Department of Agriculture; DoC=Department of Commerce; DOE_ Department of Energy; DOEd=Department of Education; DOL_Department of Labor; DOT_ Department of Transportation; VA= Department of Veterans Affairs; GSA_ General Services Administration; HHS=Department of Health and Human Services; HUD= Department of Housing and Urban Development; OMB=Office of Management and Budget; NASA= National Aeronautics and Space Administration; EPA-Environmental Protection Agency; NSC=National Security Council; NSF-National science Foundation; NIEHS=National Institute of Environmental and Health Sciences; OSTP=Office of Science Technology Policy; FEMA=Federal Emergency Management Agency; CEO-Council on Environmental Quality; SI=Smithsonian Institution; NRC-National Research Council; TVA_ Tennessee Valley Authority; ICA=Intelligence Community Affairs; CEA=Council of Economic Advisors; USGS=U.S. Geological Survey; NOAA-National Oceanic and Atmospheric Administration.

SOURCE: Committee on Earth and Environmental Sciences (CEES), *Our Changing Planet: The FY 1994* **U.S.** *Global* **Change Research** *Program* **(Washington, DC: CEES, 1993).**

Box 1-C-FCCSET and USGCRP Budgets

The U.S. Global Change Research Program (USGCRP) is designed to integrate the research programs from 11 agencies through the Federal Coordinating Council for Science, Education,andTechnology (FCCSH) Committee on Earth and Environmental Saences (CEES). As a result the development of its budget within the Executive Branch follows a somewhat unusual process. USGCRP'S budget, like that of individual agencies, is negotiated through the Office of Management and Budget (OMB).The process begins with OMB supplying terms of reference that guide agency submissions. Each agency participating in USGCRP then submits detailed proposals to the CEES for what they believe to be their best contribution to the USGCRP. The Committee, with guidance from OMBand OSTP, evaluates these proposals, makes recommendations on program allocations, and returns the budget for agency comment. The CEES then prepares a recommendation to the OMB. After negotiations with participating agencies, this recommendation is integrated into the Agency Budget submission to the OMB.

Internal budget negotiations culminate with the presentation of a single budget for global change research that spells out individual agency responsibilities in detail. By evaluating agency proposals as part of an integrated program, CEES and OMB attempt to avoid duplication of effort and make optimal use of agency expertise.

An agreement that had been in effect between OMB and agencies during the first 3 years of the USGCRP required agencies to fence off monies for global change research in return for an OMB commitment to an overall funding envelope over 5 years. In effect, agency heads agreed to their global change research budgets once t he process of negotiation with OMB and CEES was complete. Thus, an agency could not reprogram global change funds if it later suffered an unexpected cut in its overall budget.

The prohibition on reprogramming global change funds ended in FY 1993. However, several workshop participants believe that agency freedom to reprogram budgets is detrimental to program financial stability. They also believe it exacerbates the problem of insufficient contributions by agencies other than NASA, which has led to a comparative lack of funding for non space-based program elements.

In September 1993, President Clinton approved the formation of the National Science and Techhnology Council. The President expects the Council to oversee the administration's research and development budget, coordinate science policy, and ensure that the administration's research and development priorities are reflected in agency budgets. According to the President's science adviser, John Gibbons, the Council will have "great powers of persuasion" as individual agencies develop their research and development budgets each year and it will operate "in parallel" with preliminary discussions between each agency and OMB.1 The effect of the Council on the FCCSET process for funding USGCRP was unclear at the time this report went to press.

1 Gimns quoted in Jeffrey Mwvis, "Clinton Moves to Manage Science," Science, vol. 261, No. 5129, *pt. 24, 1993, pp. 1666-1669.

SOURCE: office of Technology Asses.smenL 1993.

To date, funding for non space-based components of USGCRP has been difficult to secure, in part because it requires support from agencies other than NASA.[21] For example, workshop participants believe that instruments based on ground, ocean, or airborne platforms, sponsored by agencies such as NSF, NOAA, and DOE, could provide more cost-effective return on new

21 For example, participants noted thatthesuccess of U.S. participation in international programssuch as the World Ocean Circulation Experiment (W(XE), the Tropical Oceans Global Atmosphere (TOGA), and the Joint Global Ocean Flux Study (JGOFS) depended on contributions from NASA, NOAA, and the National Science Foundation (NSF). However, in a recent budget cycle, NASA received more than it asked for these programs white NOAA and NSF received no money. (To maintain these programs, NASA was forced to fill the financial gap left by inadequate funding from NOAA and NSF.)

global change finds than instrument alternatives placed in orbit as part of NASA's Earth Observing System. Others, while agreeing that non space-based elements in USGCRP should be augmented, noted that satellite-based instruments facilitate global, synoptic, and repeatable measurements of many Earth systems.

8. Gathering sufficient data to resolve global change issues requires financial and institutional commitments that transcend political and budgetary cycles.

Global change programs must be sustained for decades to study ecological system processes, to monitor the planetary energy balance and understand climate forcing and feedbacks, to monitor the storage and transport of heat within the ocean, and to monitor the movement of carbon between the oceans and atmosphere. The timescale for documenting global change vastly exceeds the periods that characterize budget and election cycles.

9. An effective global environmental monitoring network cannot be achieved without the cooperation of nations throughout the world.

A credible global environmental monitoring system would utilize satellite-based instruments, aircraft-based instruments, and literally thousands of surface-based instruments sited around the globe. It would also require countries to cooperate much more closely on global change research than they now do.

There are both scientific and practical reasons for developing such collaborations. Quantitative assessments of changes in the global environment will require systematic, continuous, long-term (decades to centuries), calibrated measurements of Earth systems. A commitment from all nations, especially those in developing regions of the world, is necessary to develop and sustain such an effort. Furthermore, international cooperation is necessary to fashion a monitoring system appropriate to different gee-political regions. Regional differences affect scientific methodology; for example, discovering appropriate indices of global change. They also have a profound influence in determing g which policies will be sustainable in the long term.

The Federal Research Program on Global Change 2

It has been nearly 5 years since the establishment of the U.S. Global Change Research program (USGCRP).1 USGCRP was instituted to respond to

> scientific data and research results that strongly indicate that there are changes in the Earth's environment that could lead to global warming, ozone depletions, changes in biodiversity and forest distributions, desertification, and other global environmental issues, all of which have potentially significant local, regional, and global effects of vital importance to mankind.[2]

The USGCRP research plan was developed by the Committee on Earth Sciences (now the Committee on Earth and Environmental Sciences), an interagency group under the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET) in the Office of Science and Technology Policy (OSTP) in the Office of the President (figure 1-1).[3] It was the first

[1] The USGCRP was formally announced as a Presidential Initiative in a January 1989 report of the Committee on Earth Sciences: *Our Changing Planet: A U.S. Strategy for Global Change Research,* which accompanied President Bush's fiscal year 1990 Budget request.

[2] Robert W. Corell, Chairman, CEES Subcommittee on Global Change Research and Assistant Director for Geosciences, National Science Foundation testimony before the House of Representatives, Committee on Science Space and Technology, Subcommittee on Space, Mar. 30, 1993.

[3] The FCCSET is composed of cabinet secretaries, deputy secretaries, and heads of independent federal agencies. The director of the White House Office of Science and Technology Policy serves as its chairman.

of several FCCSET initiatives to which the Bush administration gave the status of "Presidential Initiative.

From its inception until fiscal year (FY) 1994, three "activity streams," or program elements, defined the mission of USGCRP:[5]

1. Documentation and Analysis of Earth system changes, which includes observation—using both ground- and space-based observation systems—and data management;
2. Process Research to enhance the understanding of the physical, geological, chemical, biological, and social processes that influence Earth systems behavior; and
3. Integrated Modeling and Prediction of Earth systems processes.

In FY 1994, USGCRP officials added a fourth activity stream, Assessment.

Originally, organizers envisioned USGCRP as a complete *global change* research program, covering research on most aspects of natural and human-induced change and their impacts. However, in designing USGCRP and setting its research priorities, the Committee on Earth and Environmental Sciences (CEES) drew heavily from the existing activities of several organizations reviewing global change issues, especially the Intergovernmental Panel on Climate Change (IPCC-box 2-A).[6] This accounts, in part, for the decision by the CEES Subcommittee on Global Change Research, which is responsible for the overall direction of the USGCRP, to designate research programs aimed at improved understanding of Climate and Hydrologic Systems as USGCRP'S highest priority (figure 2-l).

CEES evaluates USGCRPprograrns according to several criteria: relevance and contribution to the overall goals of the program, scientific merit,

Box 2-A-The Intergovernmental Panel on Climate Change

The Intergovernmental Panel on Climate Change (IPCC), chartered in 1988, is an intergovernmental body Sponsored jointly by the World Meteorological Organization and the United Nation's Environmental Programme. The group's three working groups are charged with:

1. assessing thescientific understanding of natural and human-hduoed climate change;
2. assessing likely impacts resulting from such change; and
3. considering possible response strategies for limiting or adapting to climate change.

In 1990, the IPCC produced three documents outlining the current state of knowledge about climate change entitled: ***The IPCC Scientific Assessment,*** The ***IPCC Impacts Assessment*** and the ***IPCC Response Strategies*** The IPCC pubished an update of the science assessment in 1992 and is scheduled to complete another full assessment in 1995.

SOURCE: Office of Technology Assessment,1993

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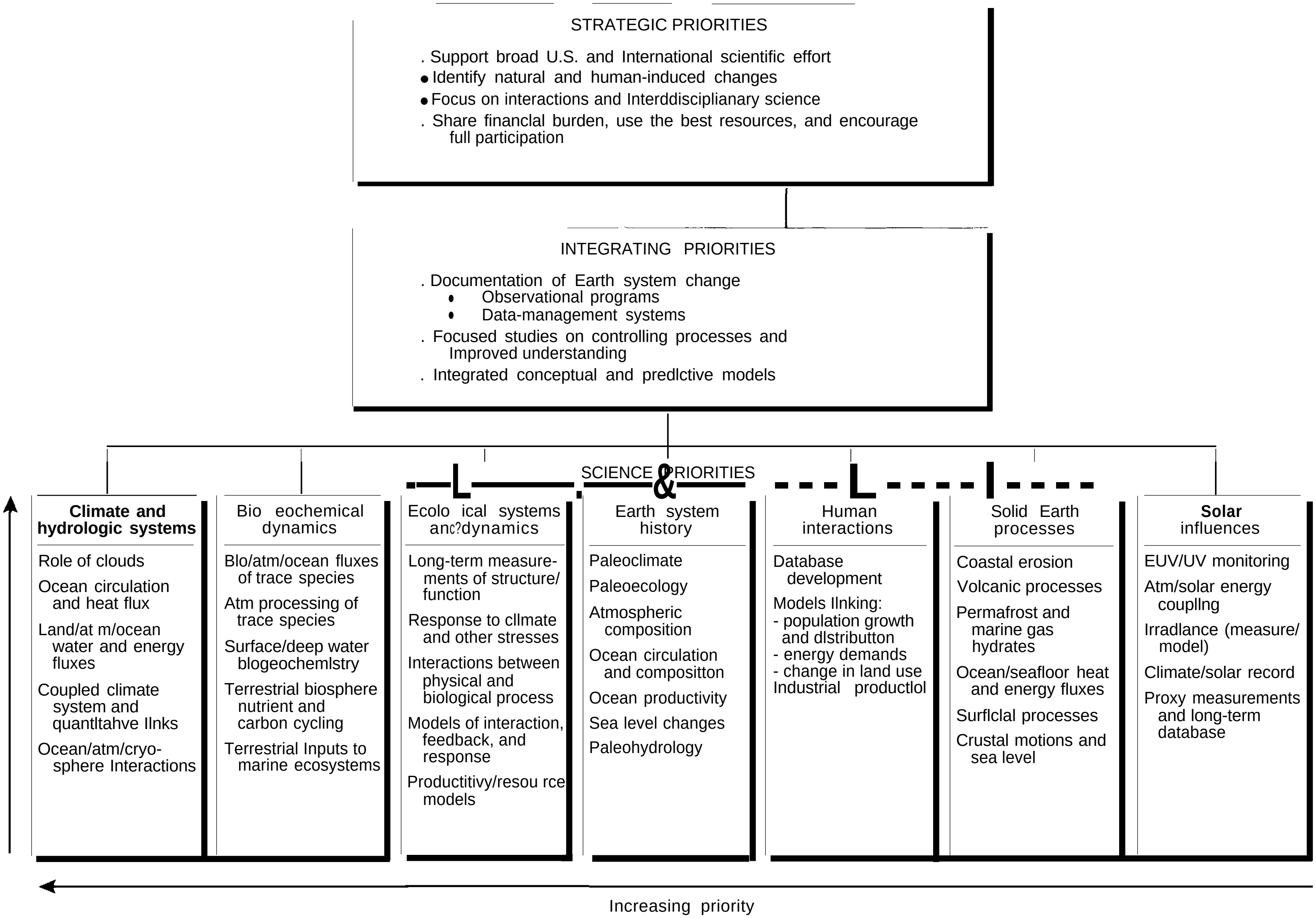
[4] The Clinton administration now refers to these as Strategic Initiatives. They are: advanced materials and processing, high performance computing and communications, global climate change, manufacturing technology and science, biotechnology research and science, and math and engineering education. D. Allan Bromley, Assistant to then President Bush for science and technology, developed the FCCSET initiatives as a means to pursue a select few high-profile, relatively high cost programs, requiring coordination among multiple Federal agencies and departments.

Some scientists, especially in academia, have criticized FCCSET's focus on a few applied research and technology initiatives on grounds that they divert funds from basic research, Proponents of the FCCSET initiatives counter that basic research may, in fact, benefit from FCCSET initiatives because basic research performed in support of a highly visible applied objective is more likely to be immune from congressional or agency funding reallocations.

[5] Committee on Earth and Environmental Sciences (CEES), *Our Changing Planet: The FY 1994 U.S. Global Change Research Program* (Washington, DC: CEES, *1993).*

[6] *In* addition to the IPCC, USGCRP was influenced by studies undertaken by National Academy of Sciences @AS), the World Climate Research Program (WCRP) of the World Meteorological Organization (WMO), the International Council of Scientific Unions (ICSU), and the International Geosphere-Biosphere Program (IGBP).

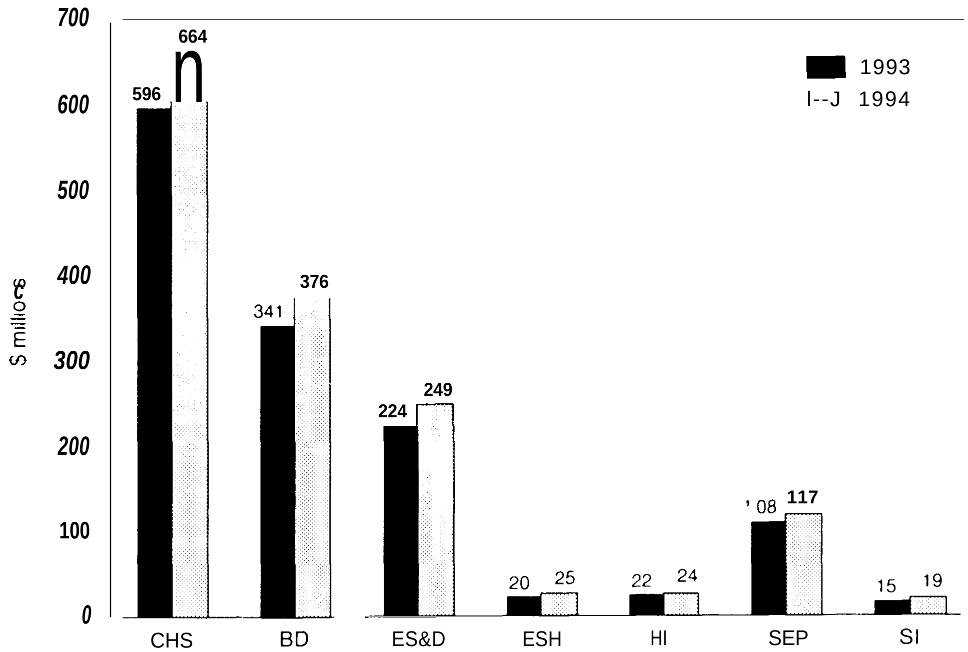
Figure 2-I—Priority Framework for USGCRP



NOTE: atm=atmosphere; EUV/UV=extreme ultraviolethltraviolet.

SOURCE: Committee on Earth and Environmental Sciences (CEES), *Our Changing* Planet: The FY **1993 U.S. G/oba/** *Change Research Program* **(Washington, DC: CEES, 1992).**

Figure 2-2–USGCRP Budget by Science Element



NOTE: CHS=Climate and Hydrologic Systems; BD=Biogeochemical Dynamics; ES&D=Ecological Systems and Dynamics; ESH=Earth System History; HI=Human Interactions; SEP=Solid Earth Processes; SI=Solar Influences. FY 1994 values are the requested, not the appropriated, amounts.

SOURCE: Committee on Earth and Environmental Sciences (CEES), *Our Changing Planet: The FY 1994 U.S. Global Change Research Program* (Washington, DC: CEES, 1993).

ease or readiness of implementation, linkages to other agencies and international partners, cost, and agency approval. The priorities of the seven research areas shown in figure 2-2 and the activity streams (observation, understanding, prediction, and assessment) are intended to help guide budget decisions. To date, finding levels have followed these priority areas with the exception of assessment, which took effect in FY 1994 (figure 2-2).[7]

Eleven different Federal agencies currently contribute to USGCRP (table 2-l). They are coordinated through a budget "cross-cut' and through the presentation of participating agencies' global change budgets to the Office of Management and Budget (OMB) for considera-

[7] In FY 1993, focused research activities under the highest priority research area, Climate and Hydrologic Systems, comprised about 43 percent of USGCRP budget, Biogeochemical Dynamics (priority area 2) comprised about 24 percent, and Ecological Systems and Dynamics (priority area 3) comprised about 17 percent. Theremaining four research areas comprised about 16 of the USGCRP budget, These figures are relatively unchanged for the FY 1994 budget request. See *Our Changing Planet: The FY 1993 U.S. Global Change Research Program.*

[8] *The* budget cross-cut begins with each agency identifying preexisting research programs that pertain to the USGCRP mission. At its inception in FY 1989, approximately 70 percent of the proposed budget for USGCRP consisted of research funds from existing projects. Each agency can also propose additional ''new" research programs for inclusion in USGCRP. These programs are submitted to the Subcommittee on Global Change Research of CEES for review and then forwarded with recommendations to both OMB and the participating departments and agencies. OMB returns the USGCRP budget with its own recommendations to the agencies when it returns the whole agency budget, At that point, deliberations between OMB and the agencies proceed as normal. As agencies work to meet OMB-established budget targets, all projects, including USGCRP projects, suffer possible modification.

Table 2-l—List of Departments and Agencies or Bureaus Involved in USGCRP Research

DOC	Department of Commerce	
	NOAA	**National Oceanic** and Atmospheric Administration
DOD	Department of Defense	
	CRREL	Coid Regions Research and Engineering Laboratory
	ONR	Office of Naval Research
DOE	Department of Energy	
	OHER	Office of Health and Environmental Research
Dol	Department of interior	
	BIA	Bureau of indian Affairs
	BLM	Bureau of Land Management
	BOM	Bureau of Mines
	BOR	Bureau of Reclamation
	Fws	Fish **and Wildiife Service**
	NPS	**National Park Service**
	0 s	Office of the Secretary
	USGS	U.S. Geological Survey
EPA	**Environmental Protection Agency**	
	ORD	Office of Research and Development
HHS	Department of Health and Human Services	
	NIEHS	National institute of Environmental Health Services
NASA	National Aeronautics and Space Administration	
	OSSA	Office of Space Sciece and Applications
NSF	National Science Foundation	
	BiO	Directorate for Bioiogical Sciences
	GEO	Directorate for Geosciences
	SBE	Directorate for Social, Behavioral, and Economic Sciences
SI	Smithsonian Institution	
	iC	international Center
	NASM	National Air and Space Museum
	NMNH	National Museum of Natural History
	NZP	National Zooiogical Park
	SAO	Smithsonian Astrophysical Observatory
	SERC	Smithsonian Environmental Research Center
	STRi	Smithsonian Tropical Research institute
TVA	Tennessee Valley Authority	
	RBO	River Basin Operations
USDA	**Department of Agriculture**	
	ARS	**Agricultural Research Service**
	CSRS	Cooperative State Research Service
	ERS	Economic Research Service
		Forest Service
	: : s	Soil Conservation Service

SOURCE: Committee on Earth and Environmental Sciences (CEES), *Our Changing Planet: The FY* **1993** *U.S. Global Change Research Program* **(Washington, DC: CEES, 1992).**

tion as a single document. The principal budget review and decisionmaking body in the CEES is the Subcommittee on Global Change Research. Agencies participating in USGCRP develop their proposed contributions with guidance from CEES, OSTP, and OMB. The budget cross-cut, rarely used in the Federal Government, has been reasonably successful in facilitating cooperation and securing new funding for global change research Since the program began, the total annual USGCRP budget has grown from $660 million to its current $1.3 billion. The administration has proposed a fiscal year 1994 USGCRP budget of $1.47 billion.l"

Reducing uncertainties about the natural and human-induced changes occurring in the Earth's environment will require the study of phenomena occurring over a range of spatial scales and time scales (figure 2-3). A recurrent theme at the OTA workshop was the necessity for measurement programs that would provide both short-term information as well as multidecadal, continuous information relevant to policy and science needs.11 Several participants believed the long-term success of USGCRP rests on the resolution of several issues, including:

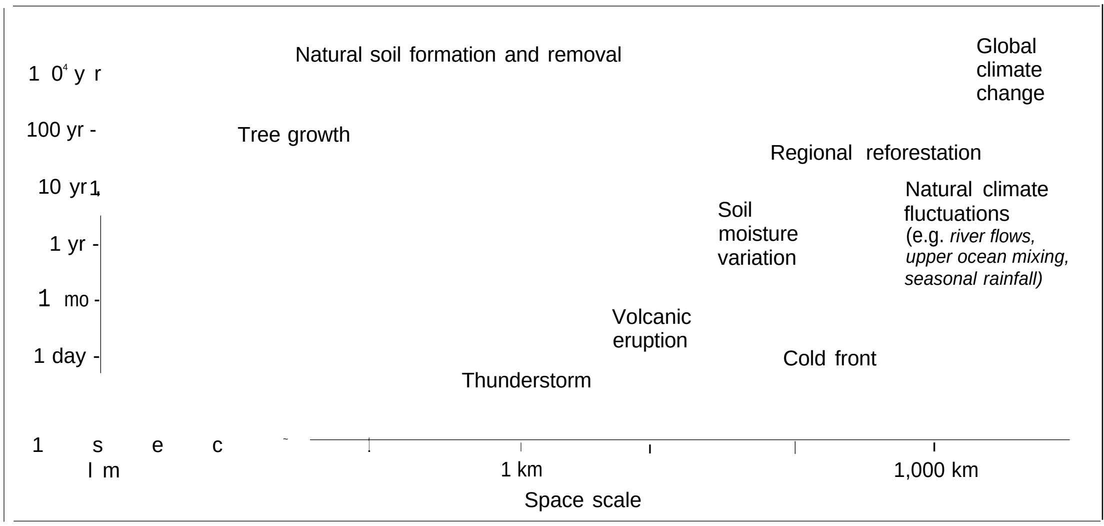
1. how best to order and review scientific priorities within and across disciplines,

[9] The National Acid Precipitation Assessment Program (NAPAP) also used such a mechanism (see app. B).

[10] Coremittee on Earth and *Environmental Sciences, Our Changing Planet,* op. cit., footnote *5.*

[11] Documents developed by CEES to direct USGCRP for the long-term indicate a desire to Sustain the program for at least 40 years. See Robert W. CoreIl, Assistant Director For Geosciences, National Science Foundation Testimony before the House of Representatives, Committee on Science, Space and Technology, Subcommittee on the Environment, May 5, 1992.

Figure 2-3-Scales **of** Natural Change



The Earth undergoes natural changes that vary from regional to global extent andover periods ranging from seconds to thousands of years.

SOURCE: GlobalChange Scaler, Quarterly Report of the Global Climate Change Program at Argonne National Laboratory. ANGCS-1, February 1993, p. 26.

2. how to broaden the program beyond its narrow focus on climate change,
3. how to ensure an appropriate balance in the participation of the National Aeronautics and Space Administration (NASA) and other agencies (especially the natural resource management agencies), and
4. how to maintain a long-term funding commitment from Congress and the administration despite the political reality of short election cycles and l-year budget cycles.

NEW DEVELOPMENTS IN USGCRP

CEES added an assessment element in FY 1994 to document the state of scientific knowledge and uncertainties and the implications of global change for the natural and human environment to support national and international policy making activities over abroad spectrum of global and regional environmental issues (figure 2-4).[12]

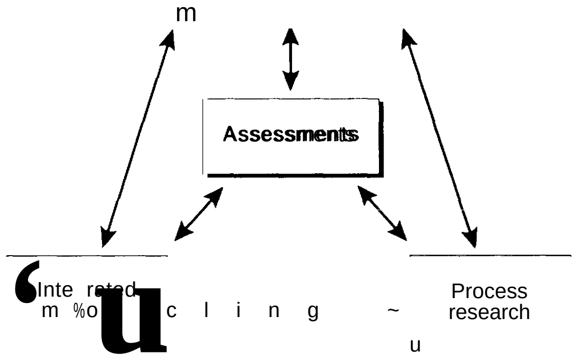
Workshop participants welcomed the explicit inclusion of an assessment element, but noted that USGCRP still lacked a detailed plan of assessment activities. Furthermore. several noted that USGCRP'S current research agenda is too narrow to support integrated (end-to-end) assessments of global change.

USGCRP focuses on understanding the physical and chemical make-up and processes of the atmosphere and places relatively little emphasis on assessing the ecological or economic impact of climate change.[13] As a result, USGCRP may not

12 See testimony of Robert W. Corell, Chairman, CEES Subcommittee on Global Change Research, before the Committee On Science, Space, and Technology, Subcommittee on Space, Mar. 30, 1993. According to Corell, these elements support the USGCRP objective to produce ''a predictive understanding of the Earth system to support national and international policymaking activities across a broad spectrum of global and regional environmental issues. '

13 Study of the impact of climate change should not be confused with study of climate sensitivity. Climate sensitivity is a high-priority area for USGCRP; for example, understanding the sensitivity of the climate system to changes in radiative forcing.

Figure 2-4-Activity Streams of USGCRP



SOURCE: Committee on Earth and Environmental Sciences (CEES), *Our Changing Planet: The FY 1993 U.S. Global Change Research Program* (Washington, DC: CEES, 1992).

be able to contribute significantly to near-term national and international policy discussions. Indeed, nearly all workshop participants agreed that USGCRP should give greater emphasis to research on the *impacts* of climate change on society and the natural world.

Workshop participants expressed a particular concern that the current emphasis on understanding atmospheric change would lead to inadequate research on understanding how biological systems might respond to climate change. For example, USGCRP'S ecological research focuses on important components of ecosystems function, but gives comparatively little attention to potential *changes in* ecosystem range, species composition, and ability to adapt to climate change. USGCRP research has also largely ignored issues of biodiversity, changes in land use, and increases in industrial pollution, addressing them only to the extent that they interact with the climate system. Nor does USGCRP examine the potential socioeconomic impacts of changes in resource production and distribution, and potential adaptation strategies for society.

Beginning in FY 1995, CEES intends to broaden the USGCRP'S research scope to address some of these concerns. New research areas could include the impacts of climate change on social systems and biological resources, as well as research on possible mitigation and adaptation strategies and technologies, topics that the original research plan explicitly left out (box 2-B).14 Policymaking would benefit if USGCRP were to include an expanded FCCSET/CEES mechanism to coordinate the various components of USGCRP and establish formal links to the policy process. The administration plans to announce complete details of this expanded USGCRP program in conjunction with the fiscal year 1995 Presidential budget request.

USGCRP officials also plan to give increased attention to the study of the socioeconomic impacts of climate change. Currently, this is supported through the Research Program on the Economics of Global Change, a distinct component of the USGCRP.[15] While workshop participants supported increased attention to the three "thrust areas" of this program they questioned the wisdom of a distinct Federal Economics Initiative.[16] In their view, the separation of this effort from the rest of USGCRP was artificial and made the study of the inherently interdisciplinary problems of global change more difficult.

BALANCE AND THE FUTURE OF USGCRP: ISSUES AND CONCERNS

Each of the agencies participating in the USGCRP decide how much research money they

14 See Corell, op. cit., footnote 12. For the original research plan, see *Our Changing Planet: The FY 1990 Research Plan*.

15 See Committee on Earth and Environmental Sciences, *Economics and Global Change: The FY 1993 Research program on the Economics of Global Change* (A Supplement to the U.S. President FY 1993 Budget) (Washington DC: Committee on Earth and Environmental Sciences, 1993)>

16 For fiscal year 1993 the three thrust areas were: 1) global economic models for the analysis of global environmental change; 2) uncertainty and the value of information; and 3) the economic effects of global change.

Box 2-B-Mitigation and Adaptation Research in the Federal Government

As originally envisioned, issues related to mitigation of, and adaptation to, global change were to be addressed under the committee on Earth and Environmental Sciences (CEES) Working Group on Mitigation and Adaptation Research Strategies (MAR- figure I-l). CEES originally excluded research on mitigation and adaptation to global change from USGCRP to keep the program primarily focused on science and clearly distinct from the policymaking process.

MARS was eliminated by 1992 despite recognition by CEES that a complementary program of mitigation and adaptation research was critical to an effective national response to global environmental issues.' Participants at the OTA workshop believed the MARS program had been largely ineffective. Among the reasons cited was the working group's lack of authority to perform a budget cross-cut, and to develop an interagency research program on mitigation and adaptation research. In addition, the MARS working group did not benefit from having the status of a Presidential initiative.

Although the MARS working group provided a forum for agencies to discuss global change programs of mutual interest it was unable to exercise any influence over project selection and funding. Consequently, MARS served primarily to catalog existing agency programs and projects that addressed mitigation, adaptation, social dynamics, and economic issues either as a main focus of a project or as a contributing element of a project. This situation might be remedied by folding some of the original MARS functions, including those designed to stimulate research on mitigation and adaptation strategies, into an expanded USGCRP or a reinstituted MARS-type program.

[1] Initial responsibility for development of a MARS program was given to EPA and DOE—two of the more "mission-oriented" agencies in the USGCRP, but, as noted above, little was accomplished. Some workshop participants attribute this partly to the previous administrations' skepticism towards the problem of human-induced global change,

SOURCE: Office of Technology Assessment, 1993.

intend to spend annually on research relevant to global change. Agency USGCRP projects are classified as "focused' '-directly relating to global change--or "contributing' justified on a basis other than global change, but having the potential to contribute to the global change knowledge base.

No standardized criteria exist for classifying contributing research, and each agency uses its own system. CEES classifies much of the research on impacts and effects—for example, the effects of drought on vegetation and the corresponding impacts to crops and ecosystems-as contributing research because agencies pursue it for reasons other than climate change. Currently, much of the Department of the Interior and the Department of Agriculture global change research consists of contributing programs not included in the USGCRP budget cross-cut of focused research programs; this includes programs to characterize ground and surface water flows and to monitor ecosystem change.

Over 50 percent of funding for focused research under the category of Ecological Systems and Dynamics supports NASA projects (e.g., Landsat and some aspects of Earth Observing System (EOS)) that primarily address ecological *functions and characterization,* rather than *impacts and effects* of climate change on ecological systems. To date, fiscal support for research on climate impacts has not been reflected in the ordering of the seven scientific research areas that guide implementation of the USGCRP. However, CEES officials expect to include more research on the social, economic, and environmental impacts of global changes in FY 1995.

The majority of USGCRP funding is embodied in NASA programs, most of which are related to environmental monitoring using satellites. In FY 1993, NASA's focused global change research programs accounted for over 60 percent of the focused global change research program budget.[17] As chapter 3 discusses, many workshop participants voiced concerns that the current EOS program ignores correlative, in situ, and process-oriented studies vital to understanding the mechanisms responsible for global change and for verifying satellite measurements.[18] In addition, they argued that program restructuring and a decrease in the EOS budget has resulted in a narrowing of the USGCRP research agenda and the sacrifice or postponement of programs necessary for the development of an effective global environmental monitoring system.[19]

Workshop participants struggled with the questions of how and where to allocate new resources for USGCRP. In terms of funding and scope, NASA has become the de facto lead agency for global change research. Thus, for example, NASA is now the lead agency not only for space-based global change measurements (its assigned role[20] but, in terms of funding, it is also the lead agency for ecological research. NASA's comparatively large budget for ecological research is a consequence of its heavy investment in satellite-based research instrumentation, and is not the result of deliberations by scientists within the ecological research community on how best to allocate Federal funds for ecological research.[21]

Agencies typically find it difficult to secure large percentage increases in their budgets. At the same time, relatively small percent increases in the NASA USGCRP budget translate into substantial funding increases relative to any other agency's budget. For example, a 5-percent increase in NASA's USGCRP budget for FY 1993 would have translated into nearly $45 million in new money whereas a 5-percent increase for the National Oceanic and Atmospheric Administration (NOAA), National Science Foundation (NSF), and the Department of Energy (DOE) would have contributed approximately $4 million, $8 million, and $5.5 million, respectively .22

USGCRP programs such as the World Ocean Circulation Experiment (WOCE), Tropical Oceans Global Atmosphere (TOGA), and the Joint Global Ocean Flux Study (JGOFS) are interagency research programs whose success depends on contributions from NASA, NOAA, and NSF. However, in a recent budget cycle, NASA received more funds than requested for these programs while NOAA and NSF received no funds. To maintain continuity in these programs, NASA was able to redirect some of its money to fill the financial gap left by inadequate funding for NOAA and NSF. The problem of securing multiple agency funding for new cross-disciplinary projects is exacerbated by a congressional authorization and appropriations process that approves agency budgets inde-

17 NSF and DOE accounted for 12 percent and 8 percent, respectively, The remaining roughly 15 percent was distributed among NOAA, DOI, USDA, EPA, DOD, the Smithsonian, HHS, and TVA.

18 The synergism between aircraft and satellite measurements is discussed in Jose M. Rodriguez, ' 'Probing Stratospheric Ozone,'' *Science*, vol. 261, Aug. 27, 1993, pp. 1128-1129.

19 That is, one that addresses the full range of environmental issues, which extend beyond just climate change.

20 The space component of the USGCRP is referred to as the S-GCOS (Space-based Global *Change Observation* System). National Space Policy Directive 7 (NSPD-7), signed by then President Bush on June 1, 1992, assigned NASA the lead role in S-GCOS. NSPD-7 directs other agencies—including the Departments of Defense, Energy, and Commerce-to cooperate in the development and operation of spacecraft and data systems. A interagency S-GCOS committee has been established to execute this directive.

21 This is reflected in the breakdown of funds by agency for USGCRP's Ecological Systems and Dynamics program element. Ecological Systems and Dynamics receives $224 million, or 17 percent of the USGCRP budget. NASA receives 66 percent of this money, while only 11 percent goes to the Department of Agriculture and 3.5 percent to the Department of the Interior.

22 Agency budgets from figure 5, "U.S. Global Change Research Program Budget by Agency, '' in *Our Changing Planet: the FY 1993 U.S. Global Change Research Program,* p. 54.

pendent of each other and has no formal mechanism to evaluate programs in their entirety.

Funding Across the Agencies

Questions of balance among USGCRP research efforts are directly related to issues involving funding allocations among participating USGCRP agencies. Currently, NASA, NOAA, and DOE control about 79 percent of the focused research budget for USGCRP.[23] The remaining funding is distributed among NSF, Department of Interior (DOI), U.S. Department of Agriculture (USDA), Environmental Protection Agency (EPA), Department of Defense (DOD), the Smithsonian, the Department of Health and Human Services (HI-IS), and Tennessee Valley Authority (TVA).

The lack of participation in USGCRP by non-NASA agencies has led to gaps in the overall program. For example, DOI, which manages large tracts of lands that could be affected severely by climate change, requested a decrease in USGCRP funds for both FY 1993 and FY 1994. DOI's position reflects a stance common to most agencies participating in USGCRP-budgets are tight and climate change does not present an immediate management concern. Another dimension of the problem of funding an appropriate mix of satellite and nonsatellite measurement programs is the historical attraction of Congress and the administration to space-based research. Workshop participants noted that Federal agencies may correctly perceive that it is easier to get financial support for large, space-based projects than for other research.[24]

M Producing Timely "Answers" for Policymakers

The timetable for governmental decisions is driven by the yearly budget cycle and an election cycle that ranges between 2 and 6 years. Not surprisingly, policymakers funding global change research often have a shorter time horizon for "answers' than researchers. This disparity leads to tension between government officials who are required to formulate anual budgets and make immediate decisions, and the scientific community, whose long-term research depends on continuous and reliable funding. Workshop participants stated that when scientists cannot answer the questions of policymakers in 1 or even a few years, they find it more difficult to "sell" a program as relevant to policy needs. The result may be annual budget fluctuations and/or rapidly shifting priorities-both of which are detrimental to the development of a sound scientific program.

23 When contributing programs are included, NASA, DOD, and NOAA account for roughly 60 percent of funding allocations

24 Even agencies doing space-based research may not necessarily be viewed as equal partners. NASA has been tasked to lead the space-based component of USGCRP, but NOAA and DOE participation is essential to complement NASA's effort. The example cited above, in which NSF and NOM received no funding for their part of an interagency program, while NASA received more than they requested for the same programs, illustrates how differently Congress may view some agencies in funding decisions.

The EOS Program 3

The Earth Observing System (EOS), the space-based component of NASA's Mission to Planet Earth (MTPE), is a series of polar-orbiting and low-inclination satellites to enable global observations of the land surface, biosphere,[1] solid Earth, atmosphere, and oceans. EOS is a central element of the U.S. Global Change Research Program (USGCRP). It is being executed by NASA as per National Space Policy Directive-7,[2]

This chapter draws on the OTA workshop to address questions related to EOS in three general areas:

1. the scientific priorities of the program;
2. the process that sets and reviews these priorities; and
3. the "balance" in the program between a) detailed studies of Earth processes and long-term monitoring, and b) ground- and air-based methods of data acquisition versus satellite-based methods.

Participants at the OTA workshop were asked a number of specific questions in these issue areas (see app. A).

THE EVOLUTION OF THE EOS PROGRAM

The principal EOS spacecraft for sensors gathering global change data are intermediate-size, multi-instrument, polar-

[1] The biosphere is the portion of the Earth and its atmosphere that can support life. Studies of the biosphere are frequently linked to studies of that part of the global carbon cycle which involves living organisms and life-derived organic matter.

[2] NSPD-7, authorized by then President George Bush in 1992, assigns to NASA the lead role in enabling global observations from space.

orbiting satellites.[3] To achieve continuous 15-year data sets, NASA plans three launches of two EOS platforms-'' AM" and "PM," indicating morning or afternoon crossing over the equator—each of which has a design life of 5 years.[4] An observation period of 15 years is long enough to observe the effects of climate change due to one sunspot cycle (11 years), several El Nino events, and perhaps the eruption of one or more major volcanoes. It should also be possible to observe some effects of deforestation and other large-scale environmental changes.

Scientists are less certain whether another 15 years of measurements will be sufficient to allow the effects of anthropogenic greenhouse gases (those that result from human activities) on Earth's temperature to be distinguished from natural background fluctuations.[5] Ecological studies of the health and migration of terrestrial systems require even longer continuous records—on the order of 20 to 50 years. As discussed below, scientists disagree on whether the EOS program currently planned will evolve into a system appropriate for such long-term monitoring.

NASA originally conceived of EOS as a program to understand Earth systems by making abroad range of environmental and Earth science measurements. In effect, the program sought to use the vantage point of space to measure as many of the variables of interest to Earth scientists as possible.[6] When NASA initiated the program in 1989, it envisioned flying 30 instruments—representing many of the Earth sciences and some Earth-related solar science-on two large spacecraft in polar orbit. The program initially had an estimated total cost of $17 billion for fiscal year (FY) 1991 through FY 2000 and involved the use of large Titan IV launch vehicles.

NASA restructured EOS in early 1992 to a program whose cost through FY 2000 would be approximately $11 billion.[7] However, EOS underwent a second revision after the FY 1993 appropriation because Congress placed a ceiling on the decadal funding of EOS of approximately $8 billion, all of the $3 billion reduction to be absorbed between FY 1994 and 2000. The nearly 30-percent funding reduction from $11 billion was also consistent with the objectives of a review ordered by NASA Administrator Daniel Goldin.

[3] EOS polar orbiters are termed ''intermediate-size' by program officials because they arc smaller than the very large satellites envisioned in the initial EOS proposal. By most standards, they are still large and expensive. For example, NASA estimates that total hardware development costs for the EOS AM-1 satellite and its sensors will approach $800 million. This figure does not include launch costs of $100 to 150 million (AM-1 requires an Atlas IIAS launcher), or ground segment and operations costs.

[4] EOS AM-1 and PM-1 will both be launched in sun-synchronous polar orbits, but with different crossing times. NASA designed the EOS-AM spacecraft primarily to observe terrestrial surface features and thus has a morning crossing time when cloud cover is minimum over land. The EOS-PM platform includes a next-generation atmospheric sounder, which is a candidate for deployment on future NOAA operational satellites, and other climate measuring instruments that are more suited towards art afternoon crossing.

[5] According to the IPCC, the unequivocal detection of an enhanced greenhouse effect is not likely to be observed for another decade or more.

[6] See Shelby G. Tilford, testimony before the Subcommittee on Space of the Committee on Science, Space, and Technology, May 6, 1993. Also see 'Earth Scientists Look NASA's Gift Horse in the Mouth,'' *Science*, vol. 259, No. 5097, Feb. 12, 1993, pp. 912-914 and U.S. Congress, Congressional Research Srevice, *Mission to Planet Earth and the U.S. Global Change Research Program*, CRS-90-300 SPR (Washington, DC: U.S. Government Printing Office, June 19, 1990), pp. 6-11 and references therein.

[7] EOS was restructured in 1992 following recommendations by the EOS Engineering Review Panel, which were also incorporated into a House-Senate conference report. By focusing on climate change instead of the broader issues addressed in the baseline program, NASA was abte to reduce to 17 the number of instruments that needed to fly by 2002. Instead of the original plan to fly two large satellites (EOS-A and EOS-B), these instruments were configured tofty ona several smaller multi-instrument polar orbiters and free flyers: 1) Three intermediate-size spacecraft series to be launched by intermediate-class expendable launch vehicles (EOS-AM, EOS-PM and EOS-CHEM); 2) one smaller spacecraft series to be launched on a medium-class expendable launch vehicle (EOS-ALT); and 3) two small spacecraft series to be launched on small launchers (EOS-COLOR and EOS-AERO).

In restructuring the EOS program, NASA chose to emphasize those global change issues the Committee on Earth and Environmental Sciences (CEES) believed to be most in need of improved scientific understanding. This affected both priorities and instrument selection.[8]

Consistent with the USGCRP, the restructured program's first priority is acquiring data on the global climate. As a result, NASA deferred or canceled programs designed to improve scientific understanding of the middle and upper atmosphere and of solid-Earth geophysics.[9] Satellite-based instruments to measure forest biomass or forest chemistry, both of which might change under climate change, were also eliminated.[10] EOS officials acknowledge that budget cuts have forced reductions in instrument contingency funds, and increased reliance on contributions from agencies other than NASA and on Japanese and European partners. According to NASA, the rescoped program has a higher risk in meeting the science objectives beyond the year 2000 because increased reliance on other agency and international collaborations is assumed, but firm commitments are still being negotiated.[11]

The restructured EOS program creates gaps in some measurement programs and risks loss of data continuity in others (box 3-A). Expected data gaps include:

- discontinuity of 5 to 7 years in most of the atmospheric chemistry measurements after the UARS satellite fails,
- discontinuity in ocean circulation measurements,
- discontinuity in Earth radiation budget experiments, and
- discontinuity in measurements of the vertical distribution of aerosols and ozone (through the SAGE instrument).

Scientists would like continuity in all of these measurements, especially those that require long time series of data to distinguish subtle trends (e.g., changes in solar output). According to NASA, EOS program officials made decisions on which instruments to orbit by weighing the consequences of having gaps in some measurements against the benefits of flying new and important instruments by the end of 1998, a date mandated by Congress.

Setting Priorities

The EOS program supports the overall USGCRP by acquiring and assembling a global database of remote sensing measurements from space. The priorities for acquiring these data conform to the seven science areas identified by USGCRP and the Intergovernmental Panel on Climate Change (IPCC) as key to understanding global climate change (ch. 2).[12] Most OTA workshop participants believed the EOS (and by extension, USGCRP and MTPE) science priorities were ordered correctly to gain a predictive understanding of the Earth system.

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[8] For example, deferral of instruments to monitor solid Earth physics, which includes crustal and ice sheet movements, was based on the relative unimportance of these processes to global climate change—the highest priority of the restructured EOS program.

[9] Elimination of missions that might provide a detailed understanding of the fundamental processes that are causing ozone depletion in the lower stratosphere increases the risk that the nation will be 1) unprepared to respond to future surprises, e.g., ozone loss over the northern hemisphere and 2) unable to implement changes in mitigation strategies. UARS, which has no direct follow-on, is not a long-term monitoring satellite—its various instruments have expected lifetimes that range from approximately 14 months to 4 years.

[10] See app. B, "The Future of Remote Sensing Technology" in U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing From Space: Civilian Satellite Systems and Applications,* OTA-ISC-558 *(Washington DC:* U.S. Government Printing Office, July 1993).

[11] It is noteworthy, however, that changes to date in EOS program direction and funding have been initiated by the United States, not its international partners.

[12] NASA's description of the role of EOS in USGCRP appears in Ghassem Asar and David Jon Dokken, eds., *EOS Reference Handbook* (Washington, DC: NASA Earth Science Support Office), March 1993.

Box 3-A-Data Gaps in EOS

Specific needs to fill data gaps include:

- Launch of a stratospherichpospheric aerosol sensor to provides data continuity between SAGE II and EOS-AERO, scheduled for launch in the year 2000.[1]
- Launch by the mid-90s of a solar irradiance sensor to ensure overlap between ACRIM (currently flying on UARS) and EOS-CHEM, scheduled for launch in the year 2002.[2]
- Launch of an "ozone watch" sensor to provide continuity between UARS and EOS-CHEM of data necessary to assess and predict ozone depletion during the period of increasing stratospheric chlorine.
- Launch of an Earth radiation budget sensor to fillthe gap incritically needed observations of radiation and cloud forcing.[3]
- Launch of an ocean altimeter to provide measurements of ocean circulation between TOPEX/Poseidon and the EOS-ALT mission in 2002.
- Launch of a precipitation mapping sensor to provide data continuity after the TRMM mission in 1997.
- Launch of an ocean color measuring sensor to fill gaps that will develop when the SeaWIFS satellite fails (SeaWiFS is scheduled for launch in 1994).[4]

Specific flights required to fill ***measurement gaps*** include:

- Launch of sensors to measure changes in the Earth's magnetic field, and to provide better map of the geoid.
- Launch of global topographic mapping sensors to provide global high resolution digital topography in support of EOS objectives. Measurement of tropospheric aerosols will also be lacking unless a focussed monitoring program is initiated.[5]

1 Unless SAGE is flown on a small satellite or on what NASA terms a "flight (missJon) of opportunity." One such flight would be on a planned NOAA weather satellite that could accommodate SAGE without necessitating expensive modification of the bus or causing significant changes in the planned instrument package. NOAA's "AM" TIROS series Isa suitable candidate; a 1997 launch might be possible if funding is identified.

2 Unless the ACRIM mission is flown on a small satellite or on a mission Of opportunity.

3 Unless it is decided to rely in part on the European SCARAB radiation budget series, which will be initiated in 1993.

4 The likelihood of a follow-on to SeaWIFS would be increased if it is successful in demonstrating the commercial value of ocean color data.

5 For example on a small satellite such as "Climsat"—see box 3-F.

SOURCE: OTA Workshop and private discussions with EOS officials.

Workshop participants differed, however, in their views of the EOS instrument selection process. As noted earlier, some participants argued strongly that the program should have set its platform and instrument priorities after consultation with a broader group of Earth scientists than those selected by NASA.[13] EOS officials point to repeated and extensive reviews by interdisciplinary panels in the selection of instruments and instrument platforms as evidence that their program was appropriately reviewed. They also note that payload selection panels followed priorities set by members who were mostly scientists who would be the users of data, rather than instrument builders hoping for approval of a particular mission.

13 One workshop participant believed the conceptual changes that would normally accompany an evolving science program have been stifled because the intellectual underpinnings of EOS (and USGCRP) relied on the professional interest and time commitments of relatively few scientists and federal managers—a group small enough that a meaningful fraction were in attendance at the OTA workshop. Furthermore, this same group has been largely responsible for implementing EOS.

Several workshop participants and reviewers of this report who were familiar with the EOS review process objected to the close ties between NASA and its program reviewers.[14] In addition, several participants argued that EOS historical legacy (the system was first proposed as an adjunct to the Space Station—box 3-B) resulted in a flawed platform and instrument selection process. In particular, they argued that the selection process was not preceded by an appropriately rigorous identification of the outstanding questions for global change research and a subsequent matching of instruments and platforms to research questions. The result, according to critics, is an Earth observation program that relies too heavily on the use of relatively large and expensive satellites. Logically, the scientific component of the EOS program should be organized around a core set of fundamental questions generated by the collective wisdom of the best minds in the international Earth science community.

1 Reviewing Priorities

Reviews of the EOS program are complicated by the necessity to consider a myriad of technology issues, data management issues, and science issues. These issues are coupled among themselves and with the overarching problem of how best to structure the program given an uncertain funding profile.[15] Workshop participants were sharply divided on the question of whether the EOS program has an appropriate process in place to review priorities and undertake program corrections. Not surprisingly, disagreements were strongest between participants who believed the EOS program had missing elements or was misdirected, and those who felt the program's review process was already overburdened.

One participant, for example, argued that EOS would benefit from frequent institutionalized scientific reviews (e.g., every 6 months). This view was seconded by another participant who argued for a standing review committee, organized within the National Academy of Sciences and the National Academy of Engineering. Workshop participants agreed that the usual Academy study, which may take 18 months to complete, is too slow to be effective. In contrast, other participants expressed concerns that frequent reviews would delay programs and divert already stretched intellectual resources. Anecdotal evidence of this problem was provided by several participants; for example, one stated that work on EOS' data and information distribution system (EOSDIS) "essentially ground to halt" during the months that the National Academy was deliberating.[16] addition, OTA was told that work on EOS slowed while the EOS Engineering Review Committee (the ''Frieman Committee") studied the program in 1991.17

Some workshop participants also warned that the EOS program could not tolerate further changes in the near term. They argued that the two program restructurings left little flexibility in the payloads and that further changes would delay critical measurements (and possibly the entire program). These participants also noted that cuts in NASA's projected EOS budget had reduced the program to the point where additions of a new

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14 For example, at least one participant believes the payload review panel (the Frieman committee) was strongly influenced by NASA Headquarters and project insiders in their deliberations. This participant questioned the independence of the committee, noting that some of the scientists on the Frieman panel were also members of particular instrument teams.

15 As noted above, NASA was instructed by Congress in the last round of budget cuts to plan to spend $8 billion on EOS during fiscal years *199* lto 2000. However, the $8 billion is a ceiling, not a floor. EOS budgets would appear to be particularly vulnerable to further budget cuts beginning in fiscal year 1995 when NASA plans to double the EOS budget to some $1 billion.

16 The NAS review of EOSDIS (the ''Zraket Committee' was chaired by Charles A. Zraket, former head of the MITRE Corp.

17 Program delays also occurred following the Frieman Committee as managers responded to recommendations by the Committee and to directions from Congress to reduce planned expenditures and adapt payloads from two large observatories to multiple smaller size satellites.

Box 3-B-Origins of the EOS Program

EOS is the principal element of NASA's Mission to Planet Earth (MTPE). The origins of MTPE and EOS can be traced to studies in the early 1960sthat considered the possibility of an international effort to study the Earth as a total system.1 The origins of MTPE were also influenced by two other developments occurring in this period: (1)the growth of the Space Station Program, (2)collaborations between NASA's Earth Sciences and Applications Division and the external scientific community that resulted in the formation of the Earth System Science Committee (ESSC) in 1963.

The ESSC, chaired by Franas Bretherton, produced a series of reports that focused on interactions of the traditional disciplines of the Earth sciences, rather than exclusively on the individual disciplines. ESSC'sactivities paralleled those being conducted by the National Academy of Sciences (NAS) in support of the 25th anniversary of the International Geophysical Year. This led to NAS proposals for comprehensive studies of the geosphere-biosphere. ESSC recommendations in 1966 for a unified study of global change were supported by NASA, NOAA, and the NSF. They were also supported by the influential NASA report, Leadership and America's ***Future in Space*** (the "Ride" report).[2]

Of particular interest for this background paper is the period in the mid-1980swhen NASA convened a group of Earth scientists to consider how they might use large human-tended satellites in low-Earth orbit. NASA planned to use the Space Shuttle, launched into polar orbit from the Western Test Range at Vandenberg Air Force Base, to maintain the satellites and change instruments. NASA offered to fund such a system of satellites-then known as System Z-out of the Space Station budget.[3] The System Z approach of using large polar platforms was also endorsed by the ESSC (which included several members of the System Z study). Part of the rationale for using large satellites was the potential to illuminate the interactions of earth processes by exploiting the capability of large satellites to carry several instruments that would acquire data on climate and other variables simultaneously.q

1 In 1982, NASA proposed a "Global Habitability" initiative at an international space conference called UNISPACE '82. However, the proposal received little support from the international community, in part because the conference became embroiled in the issue of the militarization of space. See US. Congress, Congressional Research Service, *Mission to Planet Earth and the U.S. Global Change Research program,* CRS 90-300 SPR, (Washington, DC), June 19, 1990. For a detailed discussion of the issues raised at UNISPACE '82, see US. Congress, Office of Technology Assessment, *UNISPACE '82A Context For International Cooperation and Competition,* OTA-TM-ISC-26 (Washington, DC U.S. Government Printing Office), March 1983.

2 Sally K. Ride, *Leadership and America's Future in Space: A Report to the Administrator,* (Washington, DC: U.S. National Aeronautics and Space Administration), August 1987.

3 According to officials at NASA and with the NAS, these proposals were made to increase the scientific rationale of the Space Station. See Gary Taubes, "Earth Scientists Look NASA's Gift Horse in the Mouth," *Science,* voi. 259, No. 5097, Feb. 12,1993, pp. 912-914.

4 Ibid.

instrument could occur only at the expense of one already planned.

However, as noted above, some participants believe the planned EOS is ill-suited for either long-term monitoring of key indices of global change or for mechanistic studies that might answer some of the key questions that underlie the agenda of the USGCRP. These participants believe that EOS would, in fact, benefit from a restructuring. Regardless of the scientific arguments, restructuring will be necessary if projected budgets for follow-ons to the first EOS "AM" mission do not materialize. Furthermore, tight budgets and renewed calls for a convergence of NASA, NOAA (National Oceanic Atmospheric Administration), and DOD

The connection with Space Station ended after the Challenger accident, when NASA terminated plans to launch the Space Shuttle into polar orbit. Nevertheless, the idea of using large polar platforms for studies of the Earth remained. The initial 1989 EOS proposal called for two 15-ton platforms, each carrying 12-15 instruments, which would be launched by a Titan IV rocket. NASA subsequently reduced EOS in cost and scope and distributed its instruments among a larger number of smaller (intermediate-class) satellites. These actions were taken in 1991 to respond to Congressional reductions in NASA's long-term budget projections (from $17 billion to 11 billion through FY 2000) and to ameliorate concerns about the consequences of a catastrophic failure of a *polar* orbiter.[5] Further cuts, which were part of a larger effort to control federal spending, later trimmed the decadal budget for EOS to $8 billion. This reduced program reserves and necessitated further reductions in planned science missions.

Critics of the current plan for EOS note that it evolved out of studies to match potential missions with the use of large satellites, rather than the more logical matching of scientific needs to a broad-based research program. Had EOS been designed initially to be an $8 billion program, it likely would be different than today's EOS program. NASA officials point to a series of planning meetings and program reviews which sought wide input from the scientific community as evidence that the program was organized correctly, regardless of its origins in the Space Station program.

5 Such concerns are illustrated by the recent catastrophic tosses of the NOAA polar orbiter, NOAA-J, and Landsat-6.

(Department of Defense) remote sensing sensors and-satellites may also result in a restructuring of EOS. As part of its assessment on Earth Observation Systems, OTA is exploring the potential for such convergence. A report of its findings is scheduled for spring 1994.

EOS officials acknowledged that the history of the EOS program, which includes repeated changes to account for budget cutbacks, has resulted in a program that may be less optimal than one that began from scratch. However, they believe the current program is sufficiently close to the ''right program that further modtifications would do more harm than good. In particular, they note that program restructuring would lead to delays and added costs, which might require further program rescoping.[18] Critics of this view note the long-term horizon of global change research. They argue that a program designed to last for decades will only be successful if mechanisms are in place to facilitate mid-course corrections in mission planning that account for shifting scientific priorities, changes in technology, and scientific surprises.

IS THE PROGRAM SCIENTIFICALLY SOUND?

Most OTA workshop participants agreed that research programs organized to address the outstanding scientific questions related to global change are a prerequisite for informed policymaking. However, as in the debate about whether to limit chlorofluorocarbon emissions to protect the ozone layer, policymakers will inevitably be forced to make decisions that will affect the global environment without the benefit of complete knowledge. Nevertheless, the "right' EOS and USGCRP program can bound uncertainty and thus illuminate the risks and benefits of alternative decisions.[19]

18 one workshop participant made a similar comment when asked about the effect of further budget cuts on EOS: ' 'There is a strong axiom in satellite programs that if you want to do the job for a lower sum of money, you go through a design process; you make a commitment, and then you finish it as fast as you possibly can. '

19 As one participant explained, "It is rational to proceed despite scientific uncertainties . . . provided that the actions are modest enough to fail gracefully and to discover what works through trial and error in the field. "

Some critics of the EOS program argue that the program should be focused on specific problems chosen to elucidate key areas of scientific uncertainty.[20] This view coincides with the charge that the EOS (and USGCRP) programs are operating without a ''scientific foundation, ' which would link key global change questions through a network of detailed questions to a responsive course of action (box l-A). A key objective of global change research is to achieve a level of understanding of Earth processes that would be adequate to predict future climate behavior. Several workshop participants believe this will not be possible without a different EOS program--one that would have greater emphasis on studies of processes to facilitate establishment of cause and effect.

EOS officials respond to these criticisms in several ways. First, they defend their decision to have a broad-based program as a prudent strategy to respond to scientific surprise.[21] Second, they note that program reviews have been performed by panels assembled by the National Academy of Sciences. Finally, while admitting that the list of EOS priorities is superficial from a scietific standpoint, officials note that embedded in these priorities is a detailed list of scientific questions not too different from those the critics charge is missing.

These responses did not satisfy workshop participants who cited examples of missing program elements—for example, unpiloted air vehicles to perform detailed process studies (box 3-C)--and missing instruments-for example, monitoring of solar irradiance-as evidence that the program could be strengthened scientifically. Some participants question the adequacy of EOS to answer even those scientific questions that are currently recognized.

Participants also debated whether EOS was appropriate for monitoring long-term (decade to century) climate changes. Skeptics cited several reasons to question the utility of EOS for monitoring. For example, one participant stated that: 1) the EOS measurements will not include all the major forcings and feedbacks (box 3-D)[22], 2) the EOS system will not have ready-to-launch spares and the instrument calibration plan does not include transfer of calibrations among satellites in the series, and 3) the very high cost of EOS does not make it practical to maintain the system for very long time periods. These concerns overlap other issues discussed in this chapter.

I The Role of EOS in Earth Monitoring and Process Studies

The range of Earth remote sensing research objectives can be divided into two broad categories:

1. Long-term monitoring: to determine how climate is changing, to distinguish human-induced from naturally-induced climate change (and its impacts), and to determine global radiative forcings and feedbacks.
2. Mechanistic or process studies: detailed analysis of the physical, chemical, and biological processes that govern phenomena ranging from the formation of the Antarctic ozone hole to the gradual migration of tree species.

Although these two categories cannot be clearly delineated, a process study usually extends over

20 According t. James G. Anderson, ''The idea that gathering data is equivalent to solving problems is a fallacy. YOU can collect huge amounts of data, but if those are not carefully matched to problems, then the data just gather in databanks and you make no progress. ' See "Earth Scientists Look NASA's Gift Horse in the Mouth,'' op. cit., footnote 6.

21 For example, former EOS project scientist, Jeffrey Dozier explains, ''What wehaven't done [in planning EOS] is ask a question and design an instrument to answer that question, What we have instead tried to do is design instruments with a range of measurement capabilities so they can answer a lot of questions, some of which we haven't been smart enough to ask yet. ' Dozier quoted in Science, ibid.

22 This participant suggested that the large size, high spatial resolution, and poor time sampling of EOS satellites would make them better suited for measurement of land-use, biodiversity changes, and the effects of changing population.

Box 3-C-Unpiloted Air Vehicles

Unpiloted air vehicles (UAVS) are particularly suited for making measurements at or near the tropopause, where the qualify of remotely sensed data from both ground- and space-based platforms is poor. If developed, along-endurance (multiple diurnal cycles) high-altitude UAV would become effectively a geostationary satellite at t he tropopause. The tropopause is of particular interest because it marks the vertical limit of most clouds and storms.'

Researchers interested in elucidating mechanisms for ozone depletion are partiwlariy interested in obtaining a stable, controllable, long-endurance platform that could be instrumented to monitor conditions in the stratosphere at altitudes up to and above 25 km (approximately 82,000 feet). Scientific explorations of this region are currently hampered by the uncontrollability of balloons, the inadequate altitude capabilities and high operating costs of piloted aircraft, and the inadequate measurement capabilities of most satellite instruments for the lower stratosphere. Instruments on UAVs could be changed or adjusted after each flight. UAVS, therefore, are potentially more responsive to new directions in research or to scientific surprises than are satellite systems. UAVS have also been proposed as platforms for releasing instrument packages from high altitudes, which can provide targeted measurements of climate and chemistry variables at different altitudes in the atmosphere.

High-altitude UAVS have a smaller payload capability than currently available piloted aircraft. However, they have several advantages that make them particularly attractive for climate research:

- UAVS under design should reach higher altitudes than existing piloted aircrafi. For example, NASA's piloted ER-2 can reach the ozone layer at the poles, but it cannot reach the higher altitude ozone layer in the mid-latitude and equatorial regions that would be accessible to a UAV.
- UAVS can be designed to have longer endurance than piloted aircraft.
- UAVS should have much lower operating costs than piloted aircraft.[2] (UAV studies predict savings of an order of magnitude or more.) Researchers hope the relatively low cost of UAVS compared with piloted aircraft would translate into more research aircraft and greater availability of aircraft.
- UAVS do not have the flight restrictions of piloted aircraft. For example, for pilot safet y reasons, the ER-2 is restricted to daytime fright. UAVS also alleviate concerns about pilot safety on flights through polar or ocean regions.
- UAVS would be designed to fly at high altitudes at subsonic speeds. Supersonic high altitude aircraft like the SR-71 (cruise altitude over 80,000 feet) are not suitable for many in-stu experiments because they disturb the atmosphere they are sampling {e.g., the chemical species involved in ozone depletion).

Both NASA and the Department of Energy plan to use UAVS for key experiments. in addition, the development of sensors for UAVS relates closely to the development of sensors appropriate for smallsatellites.

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1 In the tropics, the tropopause can reach altitudes of 18 km. Monitoring the tropopause with airborne platforms therefore requires vehicles capable of reaching an altitude of some 20 km. NASA's piloted ER-2 can reach this altitude, but it is restricted to frights of 6 hours. A iong duratio UAV flying at or below the tropopause would facilitate measurements necessary for global circulation models of the Earth's atmosphere and climate. These measurements would complement those being made by DOE as part of its ground-based Atmospheric Radiation Measurement Program (ARM), whose objectives are to improve models of the Earth's climate with regard to: 1) radiative energy balances, and 2) aloud formation, maintenance, and dissipation,

2 For example, direct and indirect costs to operate the ER-2 total to some $9,900/hour when calculated for a typical year of approximately 1,000 hours of flight operation. NASA considers direct costs as those associated with actually flying an aircraft and paying for support personnel. For the ER-2, these total to some $2,900/hour. This figure neglects indirect costs such as spare parts, maintenance and shipments (via cargo aircraft) to remote staging areas.

3 in their Atmospheric Radiation Measurement program.

(Continued on next page)

Box 3-C-Unpiloted Air Vehicles-Continued

Despite the potential of UAVs to enable measurements that are crucial o rglobal change research, congressional support for civillan[4] UAV development, and associated instrumentation, has been meager and maybe inadequate to provide a robust UAV capability.

EOS officials acknowledge the utility of both UAVS and small satellites (see box 3-D) in fashioning a more balanced program of Earth observations. In fact, the administration's Committee on Earth and Environmental Sciences proposed amid-course correction to the fiscal year(H) 1993 budget request that would have added money for small satellite and unmanned aircraft programs. However, these funding increments were not approved by Congress.[5]

NASA's previously tepid support for UAVS changed in 1993 when NASA Administrator Daniel Goldin proposed a large increase in the agency's UAV budget (to some $90 million over 5 years). NASA's EOS budget for FY 1993 is scheduled to double by FY 1995. Whether it will be possible to achieve this budget growth and increase funding for new starts such as UAVS remains an outstanding issue. However, several workshop participants noted that a program that cannot fund what maybe among its most cost effective science missions would appear to be in need of redirection.

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4 A variety of military UAV programs exist, some of which might be adaptable for global change research. For example, a long-endurance, solar-powered, eight-motor unpiloted flying wing that would carry lightweight interceptor missiles (dubbed Raptor/Pathfinder) is under development for applications in ballistic missile defense. However, the only military UAV that would be available in the near term for global change research would be the Boeing Condor, a large and heavy (200 foot wingspan, 20,000 pound) propeller-driven UAV that holds the altitude record for a propeller driven aircraft (67,026 feet or 20.4 km), The Condor has the range and payload capability to be useful to atmosphere scientists; furthermore, proposals existtoextend its operating ceiling to even higher altitudes. Condor would be an expensive vehicle to buy and adapt for scientific research. Even a low estimate of the oost required to restore one Condor for use in atmosphere research is some $20 million; yearly maintenance costs have been estimated at several million dollars or more.

5 AS one workshop participant, frustrated by the process that orders and funds priorities for EOS and USGCRP, explained:

> . . . aft of us within CEES (Committee on Earth and Environmental Sciences) [recognized] that the role of unmanned aircraft was important; the role of small satellites was important . . . [when] restarted to sell this program ten years agoorsixyearsago there should have been an unmanned aircraft component. *What we should have done, though, was have a generic correlative measurement component that would have then been able to adapt to a new, changing environment when new technologies came onboard.* [emphasis added]

a shorter period than a monitoring study. Process studies are typically designed to elucidate the details of a particular mechanism of some geophysical, chemical, or biological interaction. The distinction between process studies and long-term monitoring studies is least useful for studies of the land surface, which may require years or data acquisition. For example, studies of terrestrial ecosystems may require decades of calibrated observation.

OTA asked workshop participants to evaluate the utility of EOS and satellite alternatives for both long-term monitoring studies and for detailed process studies. The concluding sections of this chapter summarize some of their observations.

Monitoring STUDIES

The satellite portion of an environmental monitoring system should be designed to make continuous, long-term (decades to centuries), calibrated measurements of a carefully selected set of climatological and other variables. For most monitoring programs, global coverage will be required. In addition, measurement frequency and instrument spatial resolution must be matched to

Box 3-D–Radiative Forcings and Feedbacks

Radiative forcings are changes imposed on the planetary energy balance; radiative feedbacks are changes induced by climate change. Forcings can arise from natural or anthropogenic causes. For example, the concentration of sulfate aerosols in the atmosphere can be altered by both volcanic action (as occurred following the eruption of Mt. Pinatubo in June 1991) or by the burning of fossil fuels. The distinction between forcings and feedbacks is sometimes arbitrary; however, forcings are quantities normally specified in global climate model simulations, for example, CO_2 amount, while feedbacks are calculated quantities. Examples of radiative forcings are greenhouse gases (CO_2, CH_4, CFCS, N_2O, OS, stratospheric H_2O), aerosols in the troposphere and stratosphere, solar irradiance, and surface reflectivity. Radiative feedbacks include clouds, water vapor in the troposphere, sea-ice cover, and snow cover. For example, an increase in the amount of water vapor increases the atmosphere's absorption of long-wave radiation, thereby contributing to a warming of the atmosphere. Warming, in turn, may result in increased evaporation leading to further increases in water vapor concentrations.

The effects of some forcings and feedbacks on climate are both complex and uncertain. For example, clouds trap outgoing, cooling, Iongwave infrared radiation and thus provide a warming influence.[1] However, they also reflect incoming solar radiation and thus provide a cooling influence. Current measurements indicate t hat the net effect of clouds is to cool the Earth. However, scientists are unsure if the balance will shift in the future as the atmosphere and cloud formation, maintenance, and dissipation are altered by the accumulation of greenhouse gases. Similarly, the vertical distribution of ozone (O_3) affects both the amount of radiation reaching the Earth's surface and the amount of reradiated infrared radiation that is trapped by the greenhouse effect. These two mechanisms affect the Earth's temperature in opposite directions. Predicting the climate forcing resulting from ozone change is difficult because the relative importance of these two competing mechanisms also depend on the altitude of the ozone change.

[1] For a more detailed discussion of these subjects see V. Ramanathan, Bruce R. BarkStrom, and Edwin Harrison, "Climate and the Earth's Radiation Budget," Physics Today, vol. 42, No, 5, May 1989, pp. 22-32. Also see J. Hansen, W. Rossow, and 1. Fung, "Long-Term Monitoring of Global Climate Forcings and Feedbacks," Proceedings of a Workshop heid at NASA Goddard Institute for Space Studies, Feb. 3-4, 1992.

SOURCE: Office of Technology Assessment, 1993.

the phenomena under study, The decades of measurements required by many monitoring programs exceed the lifetime of any single satellite; therefore, monitoring programs will require satellites to be flown repetitively. To distinguish subtle trends, a new satellite should be launched while its predecessor is still functioning. Furthermore, technical innovation in sensor or satellite design should be a lower priority than ensuring the stability of data and data analysis algorithms, In contrast, research flights for process studies require maximum flexibility. These two extremes—process-oriented studies and long-term monitoring are part of EOS' plan. However, a single system may not be appropriate for both types of measurements.

EOS instruments will acquire data on climate processes; however, study of climate *change* requires measurements over decades with full continuity and calibration of instrurnentation. In addition, the comparatively large, expensive, and high data-rate system of EOS is, according to one panelist, "fundamentally unsuited for long-term precision monitoring of global climate forcings. For example, sampling of diurnal variations will be limited because the high cost of EOS satellites prohibits flying two spacecraft in different orbits at the same time. Flying less expensive satellites would facilitate overlapping operations of satellites, which is necessary to transfer calibrations between instruments orbited sequentially as part of a decadal monitoring effort. Finally, the constrained fiscal environment of the foreseeable future makes it unlikely that an EOS level of effort and expenditure could be sustained for decades. Indeed, as noted above, further budget cuts could prevent the completion of even the planned 15 years of operations.[23]

Some panel members believe EOS should be augmented with small satellite systems specifically designed for long-term monitoring (box 3-E). The NASA Goddard Institute for Space Studies "Climsat" proposal is an example of such a system (box 3-F).[24] If successful, Climsat satellites would carry out a core group of key remote sensing measurements for many decades. Supporters of Climsat believe that the data that would be gathered by Climsat, or a similar system, are too important to be tied to the budgetary fate and schedule of EOS. Detractors of the Climsat proposal include those who believe that its funding could come only at the further expense of an already diminished EOS program. Noting that Climsat addresses only a narrow part of the climate problem, some critics also question whether data from Climsat are, in fact, more important than other data, including ocean color, land-surface productivity, atmospheric temperature and humidity, and snow and ice volume.

EOS officials acknowledge that the program is not designed for long-term monitoring. However, they argue that EOS will acquire 15 years of high-quality time-series of data that can be extended to the future as EOS research instruments are incorporated on operational satellites, such as the NOAA weather satellites. For example, eventually NOAA might fly a version of the high-resolution atmospheric' infrared sounder (AIRS), scheduled for inclusion on EOS PM-1, on its operational satellites.

MECHANISTIC OR PROCESS STUDIES

Satellites play a central role in global change research because they facilitate global, synoptic, and repeatable measurements of many Earth systems. For economic reasons, surface-based measurements cannot provide similar coverage. In addition, regular monitoring of remote parts of the globe is impractical using surface-based instruments.

Satellite sensors may be employed to monitor changes in global biomass, land use patterns, and in the oceans and remote continental regions. They can also be used for direct measurement of the regional to global scale phenomena that are the main components of the climate system. However, satellite-based measurements also have a number of limitations that restrict their utility for certain process studies.[25] These include limited spatial and temporal resolution, and an inability to sample the atmosphere (or surface) directly. Furthermore, optimizing a satellite-based sensor to improve one of these characteristics frequently requires sacrifice of the other.[26]

While satellites can examine regional interactions, balloon and aircraft-based instruments can be targeted directly on the smaller scale aspects of climate processes. Such instruments can also be

23 Evidence of this concern appeared in the debate over whether EOS "PM-1" should have been launched before "AM-l. " Concerned that "worst-case" budget cuts might force program termination after a single launch, some scientists argued for launching PM's high-priority climate measuring instruments before AM. Further evidence is seen in ongoing discussions of possible downsizing of the PM platform and possible convergence of parts of EOS with NOAA and DOD programs.

24 Box 3-F discusses the Climsat proposal to illustrate the utility of using small satellites for long-term monitoring. Competing and alternative proposals to Climsat exist; however, these were not discussed at the OTA workshop,

25 For example, satellite-borne sensors are unable to measure climatological variables to the precision necessary fOr certain numerical weather and climate models, and their ability to determine temperature, moisture, and winds is inadequate for meteorologists interested in predicting, rather than just detecting, the formation of severe storms and hurricanes.

26 For example, a satellite in low-Earth orbit wilt have a revisit time cf several days to approximately two weeks, depending on its capability to gather data from areas that are not directly below its path. High time resolution can be obtained from geo-stationary orbits (because the Earth appears motionless with respect to the satellite), but then spatial resolution and coverage are sacrificed. The high altitude of gee-stationary orbit affords a broad, but fixed and limited (e.g., no polar data), view of the Earth.

Box 3-E-Small Satellites

Small satellites have been defined as costing $100 million or less including spacecraft, instruments, launch, and operations. Workshop participants generally agreed that the EOS program should make greater use of instruments based on small satellites as a way to fill gaps between existing and planned satellites and to augment or complement data that will be acquired by larger satellites. For example, NASA's existing Earth Probes series of satellites could be augmented with a new Earth Explorer Mission series. However, such an expansion would likely require supplemental funding if NASA *were* to avoid restructuring EOS programs already approved by Congress.

Small satellites have three advantages compared to larger systems. First they are characterized by relatively low cost compared to larger satellites.1 This encourages technical innovation, which might otherwise be judged too risky. Small satellite proponents see this advantage as the key to enabling rapid, affordable augmentation and modernization of larger satellites. Second, a variety of defense and civil small satellite programs have already demonstrated that instruments, spacecraft, and launch of small environmental satellites would be possible in a program of only a few years or less, Typically, development of a small satellite avoids the potential problems associated with managing the integration of multiple instruments on a single platform. Shortening the time to launch would also add resilience to the satellite portion of the Global Change Research Program, large parts of which are frozen in development some 10 years before flight. Third, flying only a small number of instruments per satellite allows experimenters to optimize satellite orbits for a particular set of measurements.[2]

NASA, DOE and ARPA (Advanced Research Projects Agency) are examining small satellite systems for three roles in the U.S. Global Change Research Program+ 1) to address gaps in long-term monitoring needs prior to the launch of EOS satellites, 2) to provide essential information to support process studies prior to, and complementary with, the restructured EOS, and 3) to allow for innovative experiments to demonstrate techniques that greatly improve the ability to monitor key variables or improve/speed up the process studies

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1 They also weigh less and can use less costly launchers. However, launchers are not the real cost drivers in the EOS program. Multi-instrument EOS AM and PM satellites and proposed EOS facility instruments—LAWS, SAR, and HIRIS—require a launcher in the Attas 2AS-class. Launch costs with an Atlas 2AS may be some $130 million, but this is 20 percent or less of total system costs (which also includes ground segment costs).

2 However, some missions require nearly simultaneous measurements by instruments that cannot be packaged on a single satellite. In this case, a larger platform carrying several instruments maybe desirable. Another option would be to attempt to fly small satellites in dose formation.

3 See Committee on Earth and Environmental Sciences (CEES) of the Federal Coordinating Council for Science, Engineering, and Technology, *Report of the Small Climate Satellites Workshop,* (Washington, D.C.: Office of Science and Technology Policy, May 1992).

4 Ibid., pp. 20-21,

SOURCE: Office of Technology Assessment, 1993.

altered more frequently to respond to new research directions, whereas the development cycle for satellite instruments makes them more suited for longer term observation programs,

Aircraft studies of the physical and photochemical processes responsible for the formation and persistence of the Antarctic ozone hole provide an illustrative example of the kind of measurements that cannot be made from space. NASA-sponsored aircraft experiments in the winter of 1992 found very large discrepancies with conventional explanations of the mechanisms responsi-

Box 3-F-CLIMSAT

Climsat is a proposed system of two small satellites,[1] each carrying three in stmments, that would monitorthe Earth's spectra of reflected solar radiation and emitted thermal radiation. Climsat satellites would be designed to be self-calibrating, small enough to be orbited with a Pegasus-class launcher[2] long-lived (nominally 10 years or more), and relatively inexpensive.[3] Proponents believe Climsat could provide most of the missing data required to analyze the global thermal energy cycle, specifically long-term monitoring of key global climate forcings and feedbacks. In addition, proponents claim Climsat would be a more "resilient" system than EOS because it would launch a small complement of relatively inexpensive instruments on small satellites. In principle, it would be possible to continue the Climsat measurements for decades beyond the scheduled end of the EOS program.

Climsat alone could not fulfill the broader objectives of the Mission to Planet Earth and the Earth Observing System Programs. Proponents of Climsat envision combining Climsat observations, planned EOS observations, and ground-based measurements of temperatures, winds, humidities, aerosols, and vertical ozone. Supporters of Climsat also believe ACRIM, an instrument to monitor solar output, should be part of a long-term program to monitor global change.[4]

Both the baseline EOS program and the baseline Climsat proposal have been revised since their initial presentations. Versions of two of the three Climsat instruments are nowscheduledfor later EOSflights. However, Climsat supporters argue that flying these instruments as part of Climsat would:

- Allow flight in proper orbits.
- Guarantee overlapping operations (over longer periods), which would result in better calibrated measurements.
- Allow launch several years before the relevant EOS platforms!
- Allow instrument modification on a shorter time-scale than EOS instruments and thus be better able to respond to scientific surrprises. Supporters also argue that Climsat instruments are better designed to handle scientific surprises because:
  1. Unlike related larger instruments on EOS, they cover practically the entire reflected solar and emitted thermal spectra.
  2. The Climsat instruments measure the polarization as well as the mean intensity of the solar Spectrum.[6]

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1 AS described below, the baseline Climsat proposal specifies this number because it is necessary and sufficient for global coverage and for adequate sampling of diurnal variations.

2 A launch on Pegasus costs about $10-12 million. Pegasus can carry payback weighing Up to 900 pounds.

3 Cost estimates are uncertain at an early stage of concept definition. However, two of the three Climsat Instruments have gone through phase A/B studies in EOS, leading Goddard Institute of Space Studies researchers to make the following estimates:

SAGE III—$34 million for 3 EOS copies (18 million for first copy);
EOSP—$28 million for 3 EOS copies ($16 million for first copy);
MINT—$15 to 20 million for first copy.

4 The primary objective of ACRIM Is to monitor the variability of total solar irradiance with state-of-the-art accuracy and precision, thereby extending the high-precision database complied by NASA since 1980, Maintaining a continuous record of solar irradiance and launching sensors frequently enough to have overlapping operation (to transfer calibration) is necessary to distinguish subtle variations in solar output. However, the only ACRIM sensor now in orbit is on UARS, a satellite whose useful lifetime is expected to end in 1994. NASA plans to launch ACRIM as part of the EOS-CHEM payload, but EOS-CHEM is not scheduled for launch until the third quarter of 2002. if funds can be identified, EOS program officials hope to launch ACRIM earlier on a "flight of opportunity." Climsat supporters would fly ACRIM as soon as possible on a separate small satellite.

5 According to Dr. James Hansen, developer of the Climsat proposal, the Climsat satellite would require three years to build and launch after approval and procurement processes were complete.

6 polarization refers to the directional dependence of the electrical field vector Of electromagnetic radiation. Analysis of the polarization of reflected light oan provide unique Information about scene characteristics. it can also determine aerosol characteristics. See discussion of Climsat and EOSP in app. B of *The Future of Remote Sensing from Space: Civilian Satellite Systems and Applications*, ORA-ISC-558 (Washington, DC: US. Government Printing Office, Jufy 1993).

ble for ozone depletion.[27] This result was very surprising; moreover, explanations for the discrepancies showed that simultaneous high-resolution observations (on the scale of 0.1 kilometer in vertical extent) of the concentration of multiple chemical species were necessary to diagnose the operative mechanisms properly.

EOS AND BALANCE WITHIN THE USGCRP

OTA workshop participants generally agreed that the USGCRP would benefit from a more balanced program between satellite and other types of studies. Forexample, participants strongly urged greater support for correlative (''ground-truth' measurements that would support and complement satellite measurements. As noted above, many also urged greater support for process-oriented studies to facilitate establishment of the physical and chemical mechanisms responsible for global change. The need for a long-term monitoring system has also been noted in this paper.

Several workshop participants attributed deficiencies in the USGCRP to the failure of agencies charged with nonsatellite research to acquire resources necessary to fulfill roles anticipated in the original formulation of the Program. Attempting to redress this problem either through redirection of NASA funds, or through funding increments, raises several policy issues whose resolution is beyond the scope of this background paper. They include:

- Should NASA be the lead agency for both space and non-space based measurements?
- If not, will agencies other than NASA embrace USGCRP as a priority and give nonsatellite programs sufficient attention and funding?
- Is NASA, which has traditionally been responsible for research and development of space technology, the appropriate agency to be charged with long-term environmental monitoring?
- Is it realistic to expect Congress to appropriate large percentage increases in agency global change budgets? If not, does NASA become the de facto lead agency for both space-based and non space-based programs? What consequences might arise from NASA assuming these roles?
- Would requiring agencies to "fence off' their contributions to the USGCRP result in greater support for non-satellite programs?

27 Analysis of in-situ measurements of chlorine monoxide at mid- and high northern latitudes during the period October 1991 to February 1992 indicates that chlorine species play a greater role, and oxides of nitrogen a lesser role, than previously thought in the catalytic destruction of ozone in the lower stratosphere. See D.W. Toohey et. al., "The Seasonal Evolution of Reactive Chlorine in the Northern Hemisphere, " *Science*, vol. 261, No. 5125, Aug. 27, 1993, pp. 1134-1135.

Appendix A: OTA's Workshop Premise and Questions to Participants

The U.S. Global Change Research Program (USGCRP) was formally announced as a Presidential Initiative in January 1989. Several new developments occasion OTA's workshop, which will review the organization and scientific priorities of USGCRP and its largest single element, the Earth Observing System Program (EOS). These developments include:

- The start of a new Congress with an unprecedented number of new members.
- The beginning of a new administration that includes a Vice-President who has a particular interest in the consequences of climate change.
- Executive-branch and congressional reductions that have
  - a. forced NASA's EOS program to be restructured; and
  - b. cut complementary components/new initiatives to EOS from agencies outside NASA, for example, the Department of Energy Atmospheric Radiation Measurement program and advanced technology demonstrations proposed by the Department of Defense (DOD).

OTA recognizes that USGCRP and EOS programs are the result of lengthy reviews and difficult compromises, Workshop participants will not be asked to pass judgment on the wisdom of individual instrument selections. Instead, OTA is seeking a broad look at USGCRP and EOS to determine whether it is possible to strengthen the existing program. Most of the workshop will focus broadly on USGCRP; however, particular attention will be given to EOS and its role in USGCRP,

Questions Related to USGCRP:

- Are the science priorities of USGCRP the "right" (type, order) ones'? How well has the process that established./revised these priorities worked?
- How well is USGCRP addressing the needs of policymakers? Are new elements needed to support the assessment roles of the program?
- Are there missing elements from USGCRP (e.g., ecological research, systems appropriate for very long-term monitoring)? If so, could they be added without causing disruption to a program that already has undergone substantial revision.
- Does USGCRP have sufficient balance among ground-, ocean-, air-, and satellite-based measurements to address the most pressing scientific questions?
- Does USGCRP have a "strategic plan" that is geared to the multidecadal time frame of societaI concerns (e.g., economics and ecosystem loss). Is there an appropriate balance between near-term and long-term problems and goals? How will the end of the USGCRP as a Presidential Initiative affect plans?
- NASA's Mission to Planet Earth is the largest single element of USGCRP, making NASA the lead

[1] This appendix is the text of a memorandum submitted to workshop participants prior to their attendance at the Feb. 25-26, 1993 meeting.

agency for global change research. The contributions of other agencies in the USGCRP have fallen short of initial expectations. Can requirements for ground-, ocean-, or airborne-collected data be met without additional support from these agencies? Are there particular high-leverage initiatives that Congress should restore/initiate?

- Was USGCRP organized to insure that the broad and diverse interests of the Earth science and global change research community were addressed? What is the best way to ensure balance in the execution of the goals of the USGCRP?
- Management and utilization of natural resources under a potentially changing climate will fall to terrestrial management and research agencies such as the Department of Interior and the U.S. Department of Agriculture. Do panelists foresee greater involvement in USGCRP by these agencies?
- Certain long-lived systems, such as forests and water supply systems, will be planned with considerable uncertainty as to future climate.
  a. Will our climate research provide information with sufficient promptness to improve decision making in these areas?
  b. Are we in any way *ranking our* research efforts to provide timely information to those systems for which decisions must be made relatively promptly?

Questions Related to the EOS Program

The present $8 billion EOS program (fiscal years 1990 to 2000) evolved from what was planned to be a $17 billion program as recently as 2 years ago. Questions related to EOS and its role in the USGCRP include:

- What parts of the EOS program should now be considered "frozen; are there parts that might still be modified without substantial delays or cost penalties?
- Did a broad spectrum of the Earth science community have appropriate input into the formulation and revision of the EOS program? If not, what new relationships might be considered?
- Should NASA allocate greater resources towards nonsatellite means of data collection?
- What actions might Congress take to facilitate the development of 'smaller, faster, cheaper' missions for EOS? Does the increased risk associated with this approach (versus the traditional Phase A-D methodical approach) restrict these missions to process-oriented missions? Is smaller and lighter weight necessarily equivalent to cheaper? Are there specific actions NASA could take to facilitate technical innovation that do not require substantial increases in budget authorization?
- Are systems being developed for EOS appropriate (scientifically sound, acceptable risk affordable) for a long-term (decadal time-scale) monitoring program? Is the program structured to carry out long-term monitoring missions?
- Are the systems being developed for EOS appropriate for future operational missions, such as National Oceanic Atmospheric Administration's (NOAA) environmental satellites? Are panelists satisfied with the current arrangements between NASA and NOAA for development of NOAA satellite systems? Are NOAA interests for future operational systems being addressed in the planning of EOS?
- Is the EOS acquisition strategy flexible enough to:
  a. Withstand additional budget cuts?
  b. Withstand unexpected cost growth?
  c. Respond to science priorities that may change as early data is processed?

(Historically, budget cuts and cost growth have resulted in program delays—among the issues to be explored here is how to minimize the risk that these unexpected developments will result in gaps in the acquisition of time-series data.)

- Have budget reductions compromised EOS plans to process the expected "avalanche" of data? Are panel members satisfied that global change researchers will have adequate access to EOS data? to appropriate hardware and software? Are panelists satisfied with NASA efforts to solicit their views on questions of data policy, data analysis, data computability?
- How much of EOS will be directly relevant to assessment of ecosystem vulnerability and response to a changing climate? What parts of EOS might give us near-term guidance on policy responses? Are EOS systems a cost-effective way to acquire the required data?

Appendix B: Lessons From NAPAP

Congress passed the Acid Precipitation Act in 1980, thereby establishing an interagency task force to plan and oversee a 10-year National Acid Precipitation Assessment Plan (NAPAP).[1] The purpose of NAPAP was to increase understanding of the causes and effects of acid precipitation through research, monitoring, and assessment activities. NAPAP was intended to be useful to policymakers-the program emphasized the timely development of science for use in decision-making.[2]

NAPA.P was one of the most ambitious multiagency programs ever focused on a particular problem. Annual budgets ranged from approximately $17 million at the beginning of the program to just over $300 million at its end. Although NAPAP succeeded in its research efforts, it did not provide policy relevant information in a timely manner. This appendix focuses on the question of whether NAPAP's failure to be more "policy relevant' has lessons for the USGCRP.

When founded, NAPAP consisted of 10 task groups, each with a single agency serving as the coordination contact. Task groups included:

1. natural sources of acid precipitation,
2. human sources of acid precipitation,
3. atmospheric processes,
4. deposition monitoring,
5. aquatic effects,
6. terrestrial effects,
7. effects on materials and cultural resources,
8. control technologies,
9. assessments and policy analysis, and
10. international activities.

In 1985, the assessments and policy analysis task group was disbanded-a decision that reduced the value of the program to decisionmakers.

Policymakers looked to NAPAP for straightforward analyses of the acid rain "problem.' However, NAPAP sponsored research did not approach acid rain as a unified issue. Rather it examined the subject at a multidisciplinary and subdisciplinary level with little emphasis on synthesis of findings.

The program reported findings in excruciating disciplinary detail, an approach which was not especially helpful to non-specialist decision makers. The disciplinary pluralism of NAPAP also allowed policy advocates to pick and choose among NAPAP's reported findings, emphasizing facts or uncertainties supporting a particular position while de-emphasizing others. NAPAP

[1] NOAA, USDA, and EPA jointly chaired the task force which also consisted of members from DOI, HHS, DOC, DOE, DOS, NASA, CEQ, NSF, and TVA along with representatives of the Argonne, Brookhaven, Oak Ridge, and Pacific Northwest National Laboratories and *four* Presidential appointees.

[2] Oversight Review Board of the National Acid Precipitation Assessment Program, *The Experience and Legacy of N.MAP, Report* to *the Joint Chairs Council of the Interagency Task Force on Acid Deposition,* April 1991.

lacked an extra-disciplinary perspective that would have allowed it to characterize acid rain as a problem, non-problem, or something in between.[3]

Assessment and policy analysis research develops and uses quantitative methods to organize and communicate scientific and other information in ways that allow comparison of policy choices. These methods include decision analysis, benefit-cost analysis, risk analysis, and technology assessments. The NAFAP task group on assessments attempted to begin early in the program to develop integrated assessment methodologies and to perform multiple assessments throughout the program to assure policy relevance. For example, plans for a 1985 report included an assessment of the current damages attributed to acid deposition, an uncertainty analysis of key scientific areas, and an analysis of the implications of uncertainty for policy choices. The authors of the 1985 report were also tasked to develop a framework of the methodology for subsequent integrated assessments in 1987 and 1989.[4] However, NAPAP management changed in 1985 as did the focus of the program. The assessments task group was disbanded and responsibility for assessments moved under the &rector of research. The new director repeatedly delayed the 1985 assessment, until it was finally released (with much controversy) in 1987. The 1987 and 1989 integrated assessments were never produced. At that point, it was uncertain whether NAPAP would produce even one assessment. NAPAP ceased funding for the integrated assessment modeling because the Interagency Scientific Committee decided that they would prefer to spend limited funding on other research.

Although NAPAP eventually produced an integrated assessment in 1990, its lateness diminished its utility to policymakers formulating amendments to the Clean Air Act.[5] In addition, the effectiveness of the 1990 integrated assessment was limited as NAPAP officials either failed to execute, or underfunded, important ancillary assessments. This included, for example, an evaluation of the economic effects of acid deposition on crops, forests, fisheries, and recreational and aesthetic resources, and a determination of the implications of alternative policies.[6]

In its report to the Joint Chairs Council of the Interagency Task Force on Acidic Deposition, the Oversight Review Board (ORB) of the National Acid Precipitation Assessment emphasized strongly that an assessment function be given primacy throughout an interagency prograrn.[7] The ORB key recommendation on lessons learned about the interface between science and policy was to give assessment primacy over research since "science and research findings per se have little to offer directly to the public policy process, [and] their usefulness depends on assessment, defined as the interpretation of findings relevant to decisions."8 ORB also outlined nine other suggestions that any program with such a close interface between science and policy should follow:

1. Match institutional remedies to problems.
2. Obtain and maintain political commitment.
3. Take steps to assure continuity.
4. Configure organization and authority to match responsibility.
5. Give assessment primacy.
6. Provide for independent external programmatic oversight.
7. Understand the role of science and how to use it.
8. Take special care with communication.
9. Prepare early for ending the program.

The insights gained from the experiences of NAP' were not considered when designing the U.S. Global Change Research Program (USGCRP)-a much larger program on both a temporal and spatial scale than NAPAP. Some argue that USGCRP is following the same path as NAPAP-good research will come from

`j Hernck and Jamieson, *The Social Construction of Acid Rain: Some Implications for Science/Policy Assessment,* paper presented at the 18th annual meeting of the Society for the Social Studies of Science, Purdue, Nov. 19-21, 1992.

[4] Interagency Task Force on Acid Precipitation *Annual Report 1982 to the President and Congress* (Washington, DC: National Acid Precipitation Assessment Program, 1982).

[5] U.S. Congress, Government Accounting Office, *Acid Rain: Delays and Management Changes in the Federal Research Program* GAO/RCED-87-89 (Washington, DC: U.S. General Accounting Office, April 1987).

6 Ibid.

[7] Oversight Review Board, op. cit., footnote 2.

[8] Oversight Review Board, op. cit., footnote 2, 1191:26.

USGCRP, but the results will not be used to inform policy, and decisions concerning global change will be made with little more knowledge than that available today.[9] The logical questions to ask are: Why didn't Congress use the experiences of NAPAP in formulating legislation for USGCRP? and How should incorporation of lessons from NAPAP be integrated into USGCRP and future multiagency programs?

[9] E.S. Rubin, L.B. Lave, and M.G. Morgan, "Keeping Climate Research Relevant," *Issues in Science and Technology*, vol. 8, No. 2, Winter 1991-1992, pp. 47-55.