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Report to the Chairman, Committee on Science, House of Representatives

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EARTH OBSERVING SYSTEM

Concerns Over NASA's Basic Research Funding Strategy

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The Honorable Robert S. Walker
Chairman, Committee on Science
House of Representatives

Dear Mr. Chairman:

The National Aeronautics and Space Administration's (NASA) goal is to launch the first spacecraft of the Earth Observing System (EOS) in 1998.[1] You requested that we assess NASA's plans for funding this program and for developing its EOS-related basic research community.[2] This report (1) discusses NASA's strategy for developing such a community with specific focus on the number of currently funded EOS science investigations and (2) summarizes researchers' views on whether changes to EOS over the last few years have adversely affected their ability to carry out their interdisciplinary Earth sciences investigations. We also address issues related to the new Earth System Science Pathfinder program and its potential impact on the funding availability for future EOS investigations.[3]

Background

EOS is the centerpiece of NASA's Mission to Planet Earth, whose overall goal is to understand the total earth system (air, water, land, life, and their interactions) and the effects of natural and human-induced changes on the global environment. EOS has three major components: (1) a constellation of satellites designed to collect at least 15 years of key climate-related data; (2) a data and information system designed to operate the satellites and process, archive, and distribute the data; and (3) teams of scientists who develop algorithms for converting sensor data into useful information and conduct basic research using the information. The satellites, and data and information system, which will absorb most of the program's funding, provide the researchers with measurements that will enable them to address established research priorities.

EOS is designed to make 24 types of long-term measurements of solar irradiance and the earth's atmosphere, land cover, ice sheets, and oceans

[1]Refers to the AM-1 spacecraft. A pre-EOS-era spacecraft, the U.S.-Japan Tropical Rainfall Measuring Mission is scheduled to be launched in 1997.

[2]We addressed NASA's funding plans in NASA's Earth Observing System: Estimated Funding Requirements (GAO/NSIAD-95-175, June 9, 1995).

[3]Pathfinder is a program of low-cost space missions to do high priority Earth sciences research that is not being addressed by current programs, including EOS.

from orbiting spacecraft.[4] By 2002, when the full constellation will be in orbit, EOS will be generating data from 25 instruments on at least 10 spacecraft. Over the 20-year EOS data-collection phase, about 80 instruments will be launched on more than 30 satellites. As currently planned, the last EOS satellite will cease operations in 2020.

EOS measurements will support researchers' efforts to address Mission to Planet Earth's research priorities: (1) determine the causes and consequences of changes in atmospheric ozone; (2) improve seasonal-to-interannual climate prediction; (3) determine the mechanisms of long-term climate variability; (4) document changes in land cover, biodiversity, and global productivity; and (5) understand earth processes that can lead to natural disasters and develop risk assessment capabilities for vulnerable regions.

Mission to Planet Earth is NASA's contribution to the governmentwide U.S. Global Change Research Program.[5] An important goal of these interconnected efforts is to improve the predictive capability of numerical earth system models, especially global climate models that investigate and predict the general circulation of the atmosphere and ocean.[6] NASA has identified a potentially large and diverse "user community" for EOS-related information. Members of this community could be, for example, educators, businessmen, and public policymakers. The focus of our analysis, however, is the EOS basic research community, by which we mean NASA's currently funded EOS interdisciplinary science and instrument investigations.

In our June 1995 report, we estimated that funding requirements of the EOS baseline program would total about $33 billion for fiscal years 1991 to 2022. This estimate was developed for the program described in NASA's 1995 EOS reference handbook and included costs for satellites, launch services, data systems, science, construction of facilities, and civil service personnel. However, NASA later recognized that this program was not affordable in an environment of declining budgets and began studying ways to cut costs by using advanced technology and increasing

[4]See app. I for types of measurements; app. II for satellite missions, instruments, and measurements; and app. III for the instruments' flight schedules.

[5]Research activities of the U.S. Global Change Research Program are (1) observing the global system, (2) managing and archiving information, (3) understanding global change processes, (4) predicting global change, (5) evaluating the consequences of global change, and (6) developing tools for assessing policies and options.

[6]Global Warming: Limitations of General Circulation Models and Costs of Modeling Efforts (GAO/RCED-95-164, July 13, 1995).

collaboration with other agencies, international partners, and the commercial sector. NASA intended to use these future savings to fund more science under EOS and to reduce the program's total cost. Over the past several years, the Congress has progressively reduced NASA's planned spending on EOS for fiscal years 1990 to 2000 from $17 billion to $7.25 billion. In response, NASA changed EOS in 1991 and 1992 from a complete earth system measuring program that would have supported a wide array of global change investigations to a measurement program that will primarily support investigations of global changes to the earth's climate. For example, NASA dropped the measurement of upper atmospheric chemistry and solid earth processes. Other changes followed in order to further adjust EOS to its progressively lower budget profile through 2000. NASA officials stated the current planned spending for EOS through 2000 is about $6.8 billion.

The administration's fiscal year 1997 request for Mission to Planet Earth is $1.402 billion, of which $846.8 million is for development of EOS' data and information system, spacecraft, instruments, and algorithms. NASA's request includes $47.5 million for EOS interdisciplinary science. According to NASA's 5-year plan based on its fiscal year 1996 budget submission, NASA intends to increase spending on EOS interdisciplinary science to $73.2 million per year in fiscal year 2000.

Results in Brief

The number of currently funded EOS investigations is relatively small in comparison with two pre-EOS-era missions and the potential research opportunities afforded by EOS. NASA plans to use some of the anticipated savings resulting from improved technology and increased collaboration with others to fund more investigations. The viability of this plan is uncertain because the anticipated savings may not materialize or may be absorbed by budget reductions. If NASA's strategy for increasing funding is not successful, there may be a growing imbalance between the number of investigations NASA would like to fund and the number it can afford.

At the same time NASA wants to fund more EOS investigations, it is also planning to solicit proposals for new Pathfinder satellites. Although these satellites would focus on earth system science, they are not part of the EOS program. NASA estimates the life-cycle cost of each Pathfinder mission would not exceed $120 million over 5 years.[7] In setting the pace of the Pathfinder program, the Congress needs to assure itself that NASA has adequately demonstrated that the potential value of Pathfinder

[7]The cost estimate is for the total mission, including satellite development and launch.

investigations will exceed the potential value of additional EOS investigations that could be obtained with the same resources.

NASA's principal investigators for interdisciplinary earth system science affirmed in a 1992-93 program review that changes to EOS following the 1992 budgetary reductions would not seriously weaken their ability to conduct interdisciplinary research. They reaffirmed their view in 1995, despite further budgetary reductions and other changes in the program.

NASA's Strategy for Developing EOS' Basic Research Community

Like EOS-related space systems and information systems, the development of the EOS basic research community that will conduct interdisciplinary global climate change research requires planning. The current number of EOS investigations funded by NASA is relatively small, and NASA recognizes that it needs to increase their number, broaden the membership of EOS science teams, and take other steps to develop and sustain an EOS-era research community. NASA's strategy for developing the EOS research community is partly based on increased funding.[8] In 1995, it began efforts to fund additional investigations and to reevaluate the current investigations. NASA's ability to add more investigations is uncertain within its expected future budgets, especially if it must depend on savings from improved technology and increased collaboration with others.

Current Number of EOS Investigations Is Relatively Small

The EOS program is currently funding 29 interdisciplinary science investigations that were selected in 1989 and 1990 to use data from EOS instruments in more than one earth science discipline, such as geology, oceanography, meteorology, and climatology. Scientists associated with these investigations serve as members of the Investigator Working Group, developing detailed science plans and assisting NASA in optimizing the scientific return of the EOS mission.[9] Currently, these 29 investigations are led by 31 interdisciplinary principal investigators (2 of the interdisciplinary science investigations have coprincipal investigators). There are 354 coinvestigators associated with the 29 interdisciplinary science investigations, as well as 20 instrument principal investigators/team leaders and 197 other instrument team members.

[8]Another element of this strategy relates to the effectiveness and cost-efficiency of the EOS data and information system. See Earth Observing System: Concentration on Near-Term EOSDIS Development May Jeopardize Long-Term Success (GAO/T-AIMD-95-103, Mar. 16, 1995).

[9]NASA is wholly or partly funding 22 of these investigations, and its international partners are funding 7.

The number of EOS investigations is relatively small when compared with (1) the number of currently funded investigations associated with two pre-EOS missions—the Upper Atmosphere Research Satellite (UARS) and the U.S.-French Oceanography Satellite Ocean Topography Experiment (TOPEX/Poseidon)—to their EOS-era counterparts and (2) the ratio of the number of investigations to the raw data acquisition rate expected from instruments on EOS spacecraft to the number of investigations and raw data acquisition rates of UARS and TOPEX.

The comparison is based on the following EOS spacecraft and instruments: AM; PM; Chemistry mission (CHEM); Landsat-7; Radar ALT; Laser ALT; Stratospheric Aerosol and Gas Experiment (SAGE) III on space station; and Solar Stellar Irradiance Comparison Experiment (SOLSTICE), Active Cavity Radiometer Irradiance Monitor (ACRIM), and Clouds and Earth's Radiant Energy System (CERES) on flights of opportunity. The data rates of the EOS spacecraft and UARS/TOPEX are not strictly comparable because the instruments on the latter satellites do not directly observe the Earth. Imaging instruments are more data intensive than nonimaging instruments. However, data rate comparisons can serve as a rough indicator of the magnitude of potential research opportunities afforded by EOS and two pre-EOS-era missions. The National Aeronautics and Space Administration (NASA) used similar comparisons in its 1993 and 1995 editions of the EOS reference handbook. In the 1995 edition, NASA graphically compared the combined data rates of EOS-era satellites with the combined data rates of numerous pre-EOS-era (including UARS and TOPEX) and foreign satellites to demonstrate that the magnitude of potential research opportunities for EOS is much greater than for other combinations of Earth-sensing satellites. In its handbooks, NASA depicted the data streams flowing from the two groups of satellites to "10,000 users" in the 1993 edition and a more vaguely defined "user community" in the 1995 edition. In place of the broadly defined "users" and user community, we used the actual number of currently funded EOS, UARS, and TOPEX investigations to illustrate (1) that the magnitude of potential EOS basic research opportunities is much greater than those afforded by UARS and TOPEX (as indicated by their respective data rates) and (2) that the number of currently funded EOS investigations is small compared to the number of currently funded UARS and TOPEX investigations.

UARS, launched in September 1991, consists of 10 instruments that are measuring the composition and temperature of the upper atmosphere, atmospheric winds, and energy from the sun.[10] The UARS science investigations are led by 22 teams. NASA broadened the UARS science investigations in 1994 by selecting 40 additional teams led by “guest” investigators. It is also funding correlative measurement investigations led by 38 teams to develop an independent database to validate and complement measurements made by UARS’ instruments.[11] In the EOS era, solar energy and atmospheric chemistry measurements will be made principally by the ACRIM, SAGE, and SOLSTICE instruments and the CHEM spacecraft.[12] Currently, only 12 instrument and interdisciplinary science investigations are associated with these instruments and the CHEM spacecraft. In contrast, UARS supports research conducted by 62 instrument and science teams.[13]

TOPEX was launched in August 1992 to study the circulation of the world’s oceans. The primary instrument is an altimeter that measures the height of the satellite above the ocean, wind speed, and wave height. NASA and its French partner, Centre National d’Etudes Spatiales, selected 38 science investigations. The 38 TOPEX-related science teams have about 200 members, and NASA plans to solicit additional investigations.[14] In the EOS era, the follow-on mission to TOPEX is Radar-ALT. An instrument team has not yet been selected, but only 7 of the 29 interdisciplinary science investigations currently plan to use Radar-ALT data.

There is a large difference between the number of (1) currently funded EOS investigations and the expected volume of data from EOS and (2) the currently funded UARS and TOPEX investigations and volume of data of these

[10]The atmosphere is divided into layers based on temperature. In the bottom layer, or troposphere, temperatures decrease with height to about 10 km. The upper atmosphere consists of the stratosphere (about 10 km to 45 km), where temperatures are constant and then slowly rise with height; the mesosphere (about 50 to 80 km), where temperatures again decrease with height; and the thermosphere (no well-defined upper limit), where temperatures again increase with height.

[11]According to the administration’s fiscal year 1996 budget submission, funding for UARS’ operations and data analysis will cease in fiscal year 1998.

[12]ACRIM (1998) monitors the variability of total solar irradiance; SAGE (1998) provides profiles of aerosols, ozone, and trace gases in the atmosphere; SOLSTICE (2002) measures full disk solar ultraviolet irradiance; and instruments on the CHEM spacecraft (2002) measure, in part, tropospheric ozone. Dates are for the first flight of each instrument in the EOS era.

[13]For this comparison, the number of UARS science investigations includes 22 instrument and theoretical science investigations, and 40 guest science investigations. It does not include the correlative measurement investigations because the 38 teams associated with them were required to develop an independent database and did not have access to UARS-related data.

[14]According to the administration’s fiscal year 1996 budget submission, funding for TOPEX’ operations and data analysis will cease in fiscal year 1999.

two pre-EOS missions.[15] The combined number of the UARS and TOPEX science investigations is a little larger than the current number of EOS investigations, even though EOS' data rate (our indicator of the magnitude of potential research opportunities) is close to 1,000 times greater than the combined data rate of UARS and TOPEX. EOS will provide up to 42 million bits of data per second to 49 interdisciplinary science and instrument investigations.[16] The corresponding ratio for UARS and TOPEX is a total of 48 thousand bits of data per second to 60 investigations.[17]

NASA's Strategy to Expand EOS Research Community

The National Research Council's Board on Sustainable Development reviewed the U.S. Global Change Research Program, Mission to Planet Earth, and EOS in 1995 and stated that one of the "fundamental guiding principles" of the U.S. Global Change Research Program is an "open and accessible program" that will "encourage broad participation" by the government, academic, and private sectors.[18] Some NASA officials and EOS investigators are concerned that the Earth sciences research community perceives EOS' science teams as a "closed shop," whereby membership on a current team is a precondition for conducting future EOS-related research.

To counter this perception, NASA's current strategy to expand the EOS research community involves (1) an open data access policy and (2) efforts to broaden and change the current community by adding investigations, reevaluating the current science investigations, and recruiting new investigators.

EOS Data Policy

A vital part of the EOS data policy is that EOS data will be available to everyone: there will be no period of exclusive access for funded investigators. This has not always been NASA's policy. On some past Earth

[15]In commenting on a draft of this report, NASA provided information on data rates and data analysis and on its ongoing and planned efforts to prepare EOS investigators for handling large amounts of data and providing them with the tools for doing so. (See app. V.)

[16]"Bit," contracted from the term "binary digit," is a unit of information represented by either a zero or a one. A byte is a group of eight adjacent bits operated on as a unit and is equivalent to one character in a text file, such as the letter "a."

[17]We did not include 40 UARS guest investigations for this comparison because they were selected after UARS was launched and thus are not comparable to the current number of EOS interdisciplinary science and instrument investigations.

[18]A Review of the U.S. Global Change Research Program and NASA's Mission to Planet Earth/Earth Observing System National Academy Press (Washington, D.C., 1995), p. 8.

observing missions, funded investigators had exclusive use of the data for an extended period of time. For example, the original investigators associated with the Upper Atmosphere Research Satellite had exclusive access to the first year's data for up to 2 years. EOS data users as a rule will not be charged more than the cost of distributing data to them. The data policy contemplates a variety of potential user groups, not all of whom will be engaged in basic research. In 1995, NASA sponsored a conference to better define the user groups. The conferees identified 12 potential user groups, of which only 3 were primarily composed of scientists. The others included commercial users, resource planners, and educational groups.

NASA officials stated that about 10,000 Earth scientists might use EOS-related data.[19] Even with the large size of this potential research community and the open-access data policy, the sufficiency of EOS investigations might appear to be the least of NASA's problems. Even though 10,000 Earth scientists may be potential users of EOS data, they still need to be funded to conduct basic research. According to NASA officials, as a general rule, for this type of work, scientists analyze data when they are paid to do so.

We sought to confirm this observation by reviewing the authorship of 172 journal articles about 2 pre-EOS-era satellites—UARS and TOPEX/Poseidon. Our review showed that publicly funded investigators wrote all but 10 of the articles. We reviewed the authorship of UARS and TOPEX articles published in scientific journals from the approximate dates of launch through May 1995; these articles were selected from a database consisting of about 4,500 periodicals.[20] The principal investigators wrote 123 (72 percent) of the 172 articles. In addition, we identified two other kinds of investigators probably associated with the principal investigators and/or government funded—that is, investigators associated with the principal investigator's institution (most often a university or government agency) or another government agency. These "associate" investigators wrote 39 (23 percent) of the journal articles.

Not all people who get Earth sciences data use it to do basic research. For example, from January through May 1995, NASA's Jet Propulsion Laboratory sent 55,521 TOPEX-related data files to 28,495 requesters through the Internet. This figure does not necessarily represent separate requesters. The laboratory does not know how these requesters use TOPEX

[19]In 1994, a NASA contractor estimated the relevant U.S. science community to be between 6,100 and 11,600. See app. V for NASA's comments on the potential total EOS user community.

[20]For example, see the Journal of Atmospheric Sciences (Oct. 15, 1994) and the Journal of Geophysical Research (Dec. 15, 1994) for papers on UARS and TOPEX-related science, respectively.

data, but according to a laboratory official, data accessed through the Internet is generally not sufficient for doing basic research. Investigators want less processed data for this type of research.

Adding Investigations

NASA originally solicited proposals for EOS interdisciplinary science and instrument investigations in January 1988. The solicitation noted that NASA planned to fund 10 to 20 science investigations, with other selections possible before the launch of the first EOS platform, then scheduled for late 1995. NASA received 458 proposals in response to its solicitation, including about 250 for interdisciplinary science investigations. As previously noted, 29 interdisciplinary science and 20 instrument investigations are being funded by NASA and its international partners.[21] The lifetime of the science investigations was to extend for 4 years beyond the launch of the first satellite, or until 1999. In other words, NASA intended to add to this first group of investigations over a 10-year period (1989 to 1999). However, at a minimum, the lifetime of this first group of investigations has been extended to 13 years (1989 to 2002, including 4 years beyond AM-1's 1998 launch date).

NASA's plan to supplement the first group of science investigations with a second group within 6 years was not too optimistic given its funding expectations at that time. NASA's EOS mission planning (1982-87) took place during a time of expanding resources. During the 1980s, NASA's funding increased each year, essentially doubling from about $5 billion to $10 billion between fiscal years 1981 and 1989.[22]

NASA has recognized that more EOS investigations are needed, and last year it took a first step to add more. NASA solicited proposals in September 1995 to address, among other things, specific interdisciplinary science issues that are not well covered by existing NASA-funded investigations.[23] It received 134 interdisciplinary science proposals and hopes to add 20 to 25 investigations with grants of about $250,000 to $400,000 per year for a period of up to 3 years.

[21]See app. IV for information on the interdisciplinary science investigations.

[22]Taking the effects of inflation into account, NASA's funding increased by about 48 percent during this period. Both current and constant dollar amounts are from our report on Space Funding: NASA and DOD Activities for Fiscal Years 1981 Through 1989 (GAO/NSIAD-89-102FS, Mar. 23, 1989).

[23]The solicitation asked for 5 types of proposals: Landsat investigations, EOS instrument investigations, interdisciplinary Earth system science investigations, new investigators' investigations, and science education grant supplements. NASA received 336 proposals in response to the solicitation of which at least 12 were not considered responsive to the announcement. NASA stated in the solicitation that it intended to select from 57 to 74 investigations in the 5 areas of consideration.

NASA is funding the interdisciplinary science part of the September 1995 solicitation with a $9-million "funding wedge" created, in part, from reductions in the previously planned funding levels for some existing EOS investigations. According to a NASA official, no new money will be used to fund these investigators. It remains to be seen if NASA's ability to generate future savings in the program will become a major factor in increasing the number of EOS investigations.

Although potentially useful over the longer term, these grants will not immediately increase the number of EOS investigations in the near term because the announcement largely precludes investigators from analyzing data from the first EOS mission, AM-1, which is now scheduled for launch in 1998. Instead, NASA is asking for proposals on interdisciplinary research that primarily uses existing data sets from past satellite missions and field experiments.[24]

Reevaluating Investigations

The nature and membership of the EOS science teams has largely remained unchanged for 6 years. According to NASA officials, this longevity has created a perception among some Earth scientists that currently funded investigators constitute a "closed shop." NASA attempted to correct this perception by conducting an internal program review in 1992 and 1993 and an external peer review in 1995 and 1996. The review by EOS investigators' peers in the Earth sciences research community is not yet finished, but it could lead to the possible deselection and recompetition of some EOS interdisciplinary science teams. NASA opted for the peer review, rather than have all the current investigations reevaluated as part of a new solicitation for proposals.

NASA's 1992-93 program review found weaknesses in many interdisciplinary science teams. The reviewers generally found that only 30 percent of 23 investigations could be rated "successful" in terms of science-related assessment measures. They also noted that "most teams need work in documenting their scientific progress, plans, and the policy relevance of their research to the Earth Science community, as well as to NASA."

The reviewers specifically noted that

- 67 percent (of 24 teams) had poor management plans,
- 61 percent (of 23 teams) had a less than satisfactory publication record, and

[24]The solicitation described five interdisciplinary research issues, one of which is the implications of continued global expansion of urbanization and high-input agriculture for the environment.

- 57 percent (of 23 teams) needed to improve their contacts with the EOS instrument teams.

The review concluded that "for most teams, the biggest factor hindering their success is their lack of a good management plan—teams that do not have their own house in order will not benefit from increased collaborations" with other interdisciplinary and instrument teams.

In October 1994, the Science Executive Committee of the EOS Investigator Working Group endorsed the need for a peer review and possible turnover of teams, if this would enhance the quality of EOS investigations. The Committee, however, rejected the idea that the existing investigations should be evaluated through a new competition. It noted that a new competition could cause a loss of credibility with EOS supporters and that many interdisciplinary science teams had committed themselves "far beyond" just their science tasks.

In contrast, NASA struck a different balance between continuity and change in the pre-EOS-era U.S.-Japan Tropical Rainfall Measuring Mission. The goal of the spacecraft's three principal instruments is to measure rainfall more accurately than before, particularly over the tropical oceans.[25] The science of a long-term investigatory group was reevaluated after 3 years by holding a new funding competition for this program. NASA and Japan's National Space Development Agency first solicited research proposals in 1990 for a possible launch in 1994. Both agencies selected a total of 35 investigators. The two space agencies in October 1993 again solicited research proposals for a launch now scheduled for 1997. The space agencies selected 27 of the original investigators and added 12 new investigators to the science team.

Recruiting New Investigators

The long-term growth of the EOS research community depends, in part, on NASA's ability to recruit graduate students and newly graduated Earth scientists to use remotely sensed data. NASA supports prospective researchers in the Earth sciences through the graduate student Global Change Fellowship program. Successful candidates can be funded for up to 3 years, at $20,000 per year, primarily for tuition support and living expenses. NASA supported 112 fellowships for the 1993-94 academic year. In September 1995, NASA also established a new investigator program as part of Mission to Planet Earth and solicited proposals for 10 to 15

[25]The spacecraft also carries two EOS-funded instruments: Lightning Imaging Sensor and the Clouds and the Earth's Radiant Energy System (CERES). CERES will measure Earth's radiation budget and atmospheric radiation from the top of the atmosphere to the surface. CERES is scheduled to fly on several EOS-era spacecraft. In September 1995, NASA announced that it intends to add two new members to the mission's science team. NASA received eight proposals in response to this solicitation.

interdisciplinary investigations from recent Ph.D. recipients. The proposed investigations must be based on data from existing satellite missions. NASA received 65 proposals in response to this solicitation.

Most EOS Interdisciplinary Scientists Say Their Planned Work Is Not Severely Affected by Budgetary Turbulence

Scientists associated with EOS stated in 1994, following the program's proposed reduction to $7.25 billion, that

> while some of the multi-year reductions may be accomplished without serious effect on the program, it must be stated that the achievement of several essential elements (e.g., continuity of observations for 15 years) of the program are now at significantly greater risk.

Despite this apprehension, most interdisciplinary science investigators have experienced or expect little or no effect of budgetary turbulence on their own research. In the 1992-93 program review, NASA's investigators were generally optimistic that they could withstand EOS' continuing budgetary turbulence. In 1995, investigators reaffirmed this optimism.

Investigators' Perception of Program Changes in 1992 and 1993

As part of the 1992-93 program review, NASA asked EOS' interdisciplinary science principal investigators to evaluate the effect changes to EOS would have on their work. The reviewers classified the 23 responding investigators' remarks as follows:

- no effect (11 investigators, 48 percent);
- minor effect (8 investigators, 35 percent); and
- major effect (4 investigators, 17 percent).

The program review followed the cancellation of three major EOS instruments over several years: Laser Atmospheric Wind Sounder (observation of lower atmospheric winds); High-Resolution Imaging Spectrometer (identification of surface composition); and Synthetic Aperture Radar (high-resolution global measurements of the Earth's surface). Whether scientists planned to use a canceled instrument was a major part of how they perceived the impact on their work.

Some investigators also cited changes to their ongoing research resulting from little or no growth in most of their fiscal year 1994 budgets. According to a NASA official, only seven investigations received as much as a 10-percent increase in their 1994 budget above the amount for fiscal year 1992. One investigator, citing a flat budget for 1994, said that as a result, coinvestigators could not give full attention to EOS-related research and that it was “difficult for us to contemplate an accelerated or broadened attack on the global change problems we are addressing.” Another investigator noted that such a budget meant that “some research tasks have to be trimmed” and would not “allow much flexibility in terms of new ideas and initiatives.”

Investigators’ Perception of Program Changes in 1995

In 1995, NASA again asked the interdisciplinary science principal investigators to assess how changes over the previous 3 years to the EOS program had affected their future and ongoing research. The scientists cited the same mix of concerns as they had previously—namely, the loss of several instruments and lack of growth in their funding. One investigator noted that a 20-percent budget reduction in 1994 “decimated our attempts to carry out field studies in collaboration with [international] team members.” His view, however, was unique. Most investigators reported that the changes had so far created only relatively minor problems that could be adequately resolved.

A NASA official told us that a reason for investigators’ optimism is that NASA officials consciously tried to minimize the impact of budget reductions on EOS-related science.

New Earth System Science Pathfinder Program: Implications for EOS Science Funding

Starting in 1996, NASA plans to solicit additional Earth science research through a new Earth System Science Pathfinder program. This effort will be based on data sets collected by new satellite missions. According to NASA officials, the Pathfinder program is intended to develop quick turnaround, low-cost space missions for high priority Earth sciences research not being addressed by current programs, including EOS, thus providing an opportunity to accommodate new science priorities and to increase scientific participation in Mission to Planet Earth.

The administration is requesting $20 million for Pathfinder in fiscal year 1997 and plans to request $30 million, $75 million, and $75 million for fiscal years 1998, 1999, and 2000, respectively—a total of $200 million over the next 4 fiscal years. After then, NASA plans to offset Pathfinder’s funding requirements with reductions generated from the introduction of lower cost technology into future Mission to Planet Earth-related research. Pathfinder’s goal is to launch one mission every year, starting in 1999. NASA estimates the life-cycle cost of each mission would not exceed $120 million and would include the cost of the launch vehicle, civil service labor, investigator support, and 2 years of spacecraft operations.[26] However, NASA has not demonstrated that the potential value of Pathfinder's science would exceed the potential value of additional EOS-related science, if savings allocated to Pathfinder were allocated to EOS science.

Agency Comments and Our Evaluation

NASA criticized our analysis and conclusions. NASA stated that our draft report underestimated the size of the EOS research community and the abilities of EOS investigators to process the large amount of data expected from EOS. We do not agree with NASA' s description of our report's focus and scope. Our objective was not to estimate the size of the EOS research or broader user communities, or to assess the abilities of current researchers to handle the large amount of data expected from EOS. Rather, our objective was to assess NASA's plans for developing its basic research community, with specific focus on the number of currently funded EOS investigations. This issue is the basis for the majority of NASA's concerns. To address NASA's point, we revised our final report to clarify the specific focus and scope of our work.

NASA said that our analysis of the number of EOS investigations did not consider the broader user community. Although NASA's statement is correct, it was not the objective of our work to analyze the broader user community. We focused on comparing the number of NASA's currently funded EOS-related investigations with the number of funded investigations associated with two pre-EOS-era missions. This comparison constituted our analytic framework and formed the basis of our conclusion that the magnitude of potential basic research opportunities afforded by EOS is much greater than those afforded by UARS and TOPEX, but the number of currently funded EOS investigations is relatively small compared to the number of investigations funded under the two pre-EOS-era missions. Our conclusion is consistent with NASA's desire, as expressed in its comments on our draft report, "to expand the size of the direct EOS community," and its actions during the course of our review to increase the number of EOS investigations in a budget-constrained environment.

NASA's comments also addressed our concern about its ability to increase the number of EOS investigations based on savings from EOS and other parts of Mission to Planet Earth. NASA stated that it has already made changes to lower EOS' costs and that it will be able to decrease costs

[26]Each Pathfinder mission would have a principal investigator and a limited number of guest investigators. Considering satellite development and launch costs, only a small portion of each mission's funding would be available to pay for data analysis.

further while improving overall capability and maintaining data continuity. We have not evaluated NASA's claims in this regard.

In our draft report, we recommended that the NASA Administrator provide the Congress with an assessment of Pathfinder's potential impact on NASA's strategy for Earth system science research, including a determination that the potential value of Pathfinder's investigations is expected to exceed the potential value of additional EOS investigations. NASA generally agreed with this recommendation, stating that it would provide a strategic assessment of Pathfinder. NASA also said it planned to proceed with the Pathfinder missions on the basis of already having analyzed the tradeoffs and having had its approach validated by outside review groups. The concern that prompted our recommendation in the draft report was the availability of adequate funding for EOS basic research given NASA's funding strategy. That continues to be our concern and, in view of NASA's position, we are changing our recommendation to the NASA Administrator to a matter for congressional consideration. Our purpose in making this change is to alert the Congress to the need to address the EOS funding issue before substantial funding commitments are made to the new Pathfinder program.

NASA's comments are in appendix V.

Matter for Congressional Consideration

In judging the extent to which it should support the proposed Earth System Science Pathfinder program, the Congress may wish to have NASA demonstrate that the potential value of Pathfinder investigations will exceed the potential value of additional EOS investigations that could be obtained with the same resources.

Scope and Methodology

To accomplish our objectives, we obtained documents related to EOS' science program from and interviewed officials at NASA headquarters in Washington, D.C.; NASA's Goddard Space Flight Center, Greenbelt, Maryland; and at the Jet Propulsion Laboratory, Pasadena, California. We attended the EOS Investigators Working Group meeting in June 1995 in Santa Fe, New Mexico, and the Payload Panel meeting in November 1995 in Annapolis, Maryland.

In analyzing the development of the EOS research community, we reviewed information on pre-EOS Earth science ground- and space-based research, as well as EOS' interdisciplinary science research. In analyzing the authorship of articles related to UARS and TOPEX/Poseidon, we used "Scisearch," an international, multidisciplinary index to science literature. Scisearch indexes articles from approximately 4,500 scientific and technical journals. We used the scientists' progress reports for 1992 to 1993, and 1995 to assess whether changes to EOS have adversely affected EOS' interdisciplinary research.

We performed our work between February 1995 and February 1996 in accordance with generally accepted government auditing standards.

As agreed with your office, unless you publicly announce its contents earlier, we plan no further distribution of the report until 30 days from its issue date. At that time, we will send copies to other appropriate congressional committees; the NASA Administrator; and the Director, Office of Management and Budget. We will also make copies available to other interested parties upon request.

Please contact me on (202) 512-8412 if you or your staff have any questions concerning this report. Major contributors to this report were Brad Hathaway, Frank Degnan, Thomas Mills, Richard Eiserman, and Richard Irving.

Sincerely yours,

David R. Warren

David R. Warren
Director, Defense Management Issues

Contents

Abbreviations

ACRIM	Active Cavity Radiometer Irradiance Monitor
CERES	Clouds and Earth's Radiant Energy System
CHEM	Chemistry mission
EOS	Earth Observing System
NASA	National Aeronautics and Space Administration
SAGE	Stratospheric Aerosol and Gas Experiment
SOLSTICE	Solar Stellar Irradiance Comparison Experiment
TOPEX	U.S.-French Oceanography Satellite Ocean Topography Experiment
UARS	Upper Atmosphere Research Satellite

Twenty-Four Earth Observing System Measurement Sets

The National Aeronautics and Space Administration (NASA) considers the following measurement sets to be critical to preserving the Earth system science approach of the Earth Observing System (EOS) and important to making environmental policy decisions. The information in appendixes I-IV was derived from NASA sources.

Atmosphere Measurements

Cloud Properties

The formation, dissipation, and radiative properties of clouds influence the atmosphere's response to greenhouse forcing (i.e., mechanisms that promote the greenhouse effect). The net effect of cloud forcing and feedback determines the energy budget of Earth and its cozy temperature, which supports life.

Radiative Energy Fluxes

Earth's radiation budget drives the biological and physical processes of the atmosphere, land, and ocean, which in turn affect water resources, agriculture, and food production.

Precipitation

There is a net outflow of atmospheric moisture from the tropics to the higher latitudes. This redistribution is accomplished through evaporation and precipitation, which determine the freshwater resources for agricultural and industrial development.

Tropospheric Chemistry

Tropospheric chemistry is linked to the circulation of Earth's water (the "hydrologic cycle"), the ecosystem, and transformations of greenhouse gases in the atmosphere, thus determining the oxidizing capacity of the atmosphere for cleansing pollutants.

Stratospheric Chemistry

Stratospheric chemistry measurements involve chemical reactions, interactions between the sun and the atmosphere, and the sources and sinks of gases, such as ozone, that are critical to Earth's radiation balance.

Aerosol Properties

An aerosol is a fine solid or liquid particle suspended in gas, such as the atmosphere. Aerosols affect the climate through their radiative properties by serving as nuclei for the condensation of clouds. Aerosols tend to cool Earth's atmosphere, thus offsetting some of the warming effects of greenhouse gases.

Atmospheric Temperature

Along with atmospheric humidity, atmospheric temperature is used in short-term weather prediction and long-term climate monitoring. Improved measurement accuracy, precision, and spatial and temporal coverage will enhance weather prediction skills beyond current limits and reduce weather prediction "busts," or failures.

Atmospheric Humidity

See "Atmospheric Temperature."

Lightning

Lightning measurements will include the distribution and variability of both cloud-to-cloud and cloud-to-ground lightning. Electrical discharge contributes to the formation and dissipation of certain trace gases in the atmosphere.

Solar Radiation Measurements

Total Solar Irradiance

Sustained changes in the total radiation output from the sun could contribute to significant climate changes on Earth over time. Solar radiation is the main source of energy for biological activities on Earth.

Ultraviolet Spectral Irradiance

Out of the entire spectrum of radiation that Earth receives from the sun, the ultraviolet portion is the dominant energy source for the Earth's atmosphere. Small changes in the radiation field have an important effect on atmospheric temperature, chemistry, structure, and dynamics. Excess ultraviolet energy on the Earth's surface is harmful to living organisms.

Land Measurements

Land Cover and Land Use Change

Land use includes monitoring crops for efficient irrigation and pest control, public lands for good stewardship, and urban areas for development. Some changes in land use, such as deforestation and biomass burning, reduce the standing stock of vegetation, release carbon dioxide into the atmosphere, and reduce the capacity for the removal of carbon dioxide from the atmosphere.

Vegetation Dynamics

Terrestrial vegetation absorbs atmospheric carbon dioxide by photosynthesis to offset its greenhouse warming effect.

Surface Temperature

Terrestrial surface temperature controls the formation and distribution of atmospheric water vapor and also contributes to the determination of cloud amount. In addition, surface temperatures control the biological activity and health of agricultural fields, forests, and other natural ecosystems.

Fire Occurrence

Biomass burning releases carbon dioxide into the atmosphere and also increases concentrations of other harmful gases, such as carbon monoxide and nitrogen oxides. Land cover monitoring can be used to assess potential fire hazards and monitor fire recovery in natural ecosystems.

Volcanic Effects

The volcanic ejection of aerosols and particulates into the atmosphere can increase precipitation and ozone destruction and cause the lowering of global temperatures. Volcanic activities also contribute to the formation of continents.

Surface Wetness

Surface wetness controls the availability of fresh water resources for agricultural and industrial activities.

Ocean Measurements

Surface Temperature

Sea surface temperature measurements are important to understanding heat exchange between the ocean and the atmosphere. Such an understanding will contribute to the development of accurate general circulation models, which enhance our understanding of seasonal and interannual climate variations that contribute to hurricanes, floods, and other natural hazards.

Phytoplankton and Dissolved Organic Matter

Planktonic marine organisms and dissolved organic matter play a major role in the carbon cycle, as they incorporate, or "fix," about as much carbon as land plants. This contributes to removing carbon dioxide from the atmosphere and to offsetting the greenhouse effect.

Surface Wind Fields

Surface winds over the oceans contribute to ocean circulation and the interaction between the air and sea, which affect short-term and long-term climate variations.

Ocean Surface Topography

Sea height and ocean circulation are related. Ocean circulation transports water, heat, salt, and chemicals around the planet. Accurate information about these circulation patterns should contribute to understanding the oceans' impact on weather, climate, and marine life, and thus the fisheries industry and other maritime commerce.

Cryosphere Measurements

Ice Sheet Topography and Ice Volume Change

Measurements of the polar ice caps, including ice sheet elevation and ice volume, will determine the contribution of the ice sheets to sea-level variation. These data will also contribute to understanding the role of the polar ice caps in Earth's freshwater and energy budgets, as well as climate fluctuations.

Sea Ice

Measurements of the extent and thickness of sea ice will help determine atmospheric warming. Sea ice measurements will also be useful to operational ice forecasting centers, thus affecting maritime commerce.

Snow Cover

Snow cover, extent, and duration determine fresh water resources, especially in Alpine regions of the world.

EOS Satellite Missions, Instruments, and Measurements

Table II.1: EOS Instruments and Measurements

Instrument	Measurements
ACRIM	Active Cavity Radiometer Irradiance Monitor (ACRIM) monitors the variability of total solar irradiance.
AIRS	Atmospheric Infrared Sounder (AIRS) measures atmospheric temperature and humidity.
AMSR (Japan)	Advanced Microwave Scanning Radiometer (AMSR) observes atmospheric and oceanic water vapor profiles and determines precipitation, water vapor distribution, cloud water, sea surface temperature, sea ice, and sea surface wind speed.
AMSU	Advanced Microwave Sounding Unit (AMSU) measures atmospheric temperature.
ASTER (Japan)	Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) provides high spatial resolution images of the land surface, water, ice, and clouds.
CERES	Clouds and the Earth's Radiant Energy System (CERES) measures Earth's radiation budget and atmospheric radiation.
DFA (France)	Dual Frequency Altimeter (DFA) maps the topography of the sea surface and its impact on ocean circulation.
EOSP	Earth Observing Scanning Polarimeter (EOSP) globally maps radiance and linear polarization of reflected and scattered sunlight to measure atmospheric aerosols.
ETM+	Enhanced Thematic Mapper Plus (ETM+) provides high spatial resolution images of the land surface, water, ice, and clouds.
GLAS	Geoscience Laser Altimeter System (GLAS) measures ice sheet topography, cloud heights, and aerosol vertical structure.
HIRDLS (UK-US)	High-Resolution Dynamics Limb Sounder (HIRDLS) observes gases and aerosols in the troposphere, stratosphere, and mesosphere to assess their role in the global climate system.
LATI	Landsat Advanced Technology Instrument (LATI) provides high spatial resolution images of the land surface, water, ice, and clouds beyond Landsat ETM+.
LIS	Lightning Imaging Sensor (LIS) measures the distribution and variability of lightning.
MHS	Microwave Humidity Sounder (MHS) provides atmospheric water vapor profiles.
MISR	Multi-Angle Imaging Spectroradiometer (MISR) measures the top-of-the-atmosphere, cloud, and surface angular reflectance.
MLS	Microwave Limb Sounder (MLS) measures chemistry from the upper troposphere to the lower thermosphere.

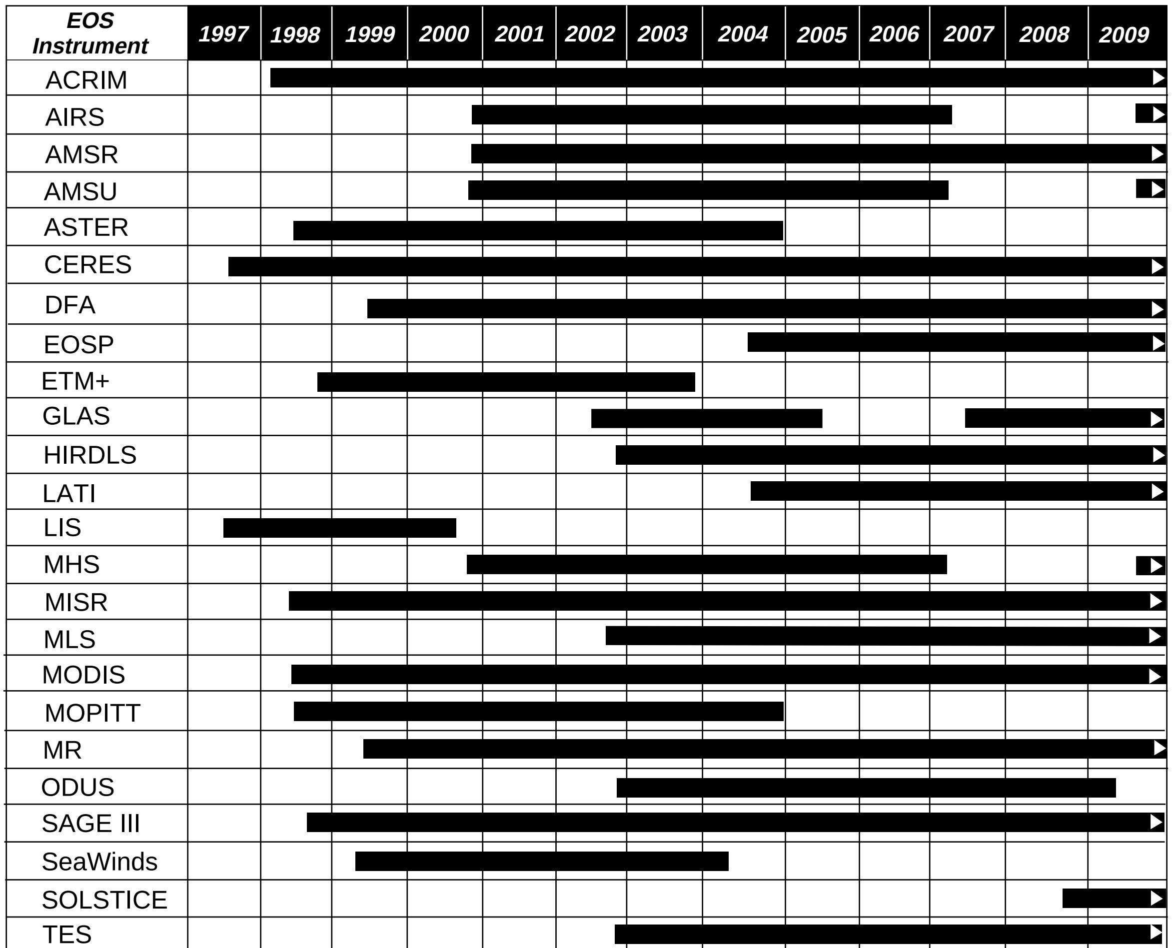
(continued)

Instrument	Measurements
MODIS	Moderate-Resolution Imaging Spectroradiometer (MODIS) studies biological and physical processes in the atmosphere, the oceans, and on land.
MOPITT (Canada)	Measurements of Pollution in the Troposphere (MOPITT) measures upwelling radiance to produce tropospheric carbon monoxide profiles and total column methane.
MR	Microwave Radiometer (MR) provides atmospheric water vapor measurements for DFA.
ODUS (Japan)	Ozone Dynamics Ultraviolet Spectrometer (ODUS) measures total column ozone.
SAGE III	Stratospheric Aerosol and Gas Experiment III (SAGE III) provides profiles of aerosols, ozone, and trace gases in the mesosphere, stratosphere, and troposphere.
SeaWinds	Provides all-weather measurements of ocean surface wind speed and direction.
SOLSTICE	Solar Stellar Irradiance Comparison Experiment (SOLSTICE) measures full-disk solar ultraviolet irradiance.
TES	Tropospheric Emission Spectrometer (TES) provides profiles of all infrared active species from Earth's surface to the lower stratosphere.

Table II.2: EOS Satellite Missions

Satellite	Description
Landsat-7 ETM+	Mission continues Landsat land-imaging satellite series. Future Landsat-type instrument is planned for AM-2 and AM-3.
AM ASTER CERES EOSP LATI MISR MODIS MOPITT	Morning equator-crossing mission (AM series) will study clouds, aerosols, and radiation balance; the terrestrial ecosystem; land use; soils; terrestrial energy/moisture; tropospheric chemical composition; volcanoes; and ocean productivity. ASTER and MOPITT will be on AM-1 only. EOSP and LATI will be on AM-2 and AM-3 only.
PM AIRS AMSR AMSU CERES MHS MODIS	Afternoon equator-crossing mission (PM series) will study cloud formation, precipitation, and radiative properties; air-sea fluxes of energy and moisture; sea-ice extent; and ocean primary productivity. The PM series will carry prototypes of future operational weather satellite instruments.
CHEM HIRDLS MLS ODUS TES	Chemistry mission (CHEM series) will study atmospheric chemical composition; chemistry-climate interactions; and air-sea exchange of chemicals and energy. ODUS will be on CHEM-1 only. A later CHEM flight may include SAGE III.
LaserALT GLAS	Laser altimeter mission (LaserALT series) will study ice sheet mass balance.
RadarALT DFA MR	Radar altimeter mission (RadarALT series) will study ocean circulation. RadarALT is a joint mission with France.
ISS, Meteor, and Flight of Opportunity SAGE III	SAGE III instrument carried on International Space Station (ISS) and Russian Meteor satellite will study distribution of aerosols, ozone profiles, and greenhouse gases in the lower stratosphere.
TRMM CERES LIS	Tropical Rainfall Measuring Mission (TRMM) will study precipitation and Earth radiation budget in the tropics and high latitudes. TRMM is a joint mission with Japan.
ADEOS-II SeaWinds	Japanese Advanced Earth Observing System II (ADEOS II) satellite carrying NASA scatterometer instrument will study ocean surface wind vectors.
ACRIM ACRIM	Mission will monitor the variability of total solar irradiance and is currently planned to fly on a series of small satellites.
Flight of Opportunity CERES	Mission will study Earth's radiation budget and atmospheric radiation.
Flight of Opportunity SOLSTICE	Mission will study full-disk solar ultraviolet irradiance.

EOS Instrument Flight Schedule Through 2009



• Timeline bars denote periods during which at least one copy of the indicated instrument is in orbit.

EOS Science Objectives and Interdisciplinary Investigations

EOS science objectives are listed below, along with the interdisciplinary investigations designed to address them. These investigations are intended to cross discipline boundaries, and therefore, address more than one science objective.

The **Water and Energy Cycles** objective covers the formation, dissipation, and radiative properties of clouds, which influence the atmosphere's response to greenhouse forcing. In addition, Water and Energy Cycles include large-scale hydrology and moisture processes, such as precipitation and evaporation.

- National Center for Atmospheric Research Project to Interface Modeling on Global and Regional Scales With EOS Observations. This investigation is intended to use surface and atmospheric data sources to improve climate models and their predictions of global change. Components of climate models to be addressed include surface-atmosphere interactions, the hydrologic cycle, global energy balance, cloud and aerosol radiative fields, and atmospheric chemical cycles.
- Climate Processes Over the Oceans. Climate is strongly influenced by the amount and distribution of water vapor, liquid water, and ice suspended in the atmosphere. This atmospheric water, and the climate over land areas, is largely controlled by processes occurring over the oceans. This investigation will improve modeling of both the atmosphere and its interactions with the ocean. It will address the roles of circulation, clouds, radiation, water vapor, and precipitation in climate change as well as the role of ocean-atmosphere interactions in the energy and water cycles.
- Hydrologic Processes and Climate Interdisciplinary Investigation. The global water and energy cycles link the atmosphere, land, and ocean. In addition, water supports life and plays a crucial role in climate regulation. This investigation is to enhance our understanding of the physical processes that affect these cycles.
- The Processing, Evaluation, and Impact on Numerical Weather Prediction of AIRS, AMSU, and MODIS Data in the Tropics and Southern Hemisphere. This investigation involves the development of algorithms and techniques to improve atmospheric science, specifically numerical weather prediction models, using three EOS instruments.
- Investigation of the Atmosphere-Ocean-Land System Related to Climate Processes. The atmosphere, ocean, and land interact with each other through the exchanges of heat energy, momentum, and water substance. These interactions influence climate. This investigation will examine the atmosphere-ocean-land system by pursuing seven supporting studies that will involve both observations and modeling.

- The Development and Use of a Four-Dimensional Atmospheric-Ocean-Land Data Assimilation System for EOS. This investigation will incorporate all available data, from a variety of sources, into a single model of the Earth system. This model can then be used to project the Earth system beyond the range of actual observations, estimate expected values of observations to assess instrument quality, provide products for environmental studies, and supplement observations by estimating quantities that are difficult or impossible to observe.
- An Interdisciplinary Investigation of Clouds and the Earth's Radiant Energy System: Analysis. This investigation will examine the role of clouds and radiative energy balance in the climate system. Studies include cloud feedback mechanisms that can greatly modify the response of the climate system to increased greenhouse gases.

The **Oceans** objective covers the exchange of energy, water, and chemicals between the ocean and atmosphere, and between the upper layers of the ocean and the deep ocean.

- Coupled Atmosphere-Ocean Processes and Primary Production in the Southern Oceans. The southern ocean plays an important role in both the carbon cycle and heat exchange between the ocean and atmosphere. This investigation will focus on developing predictive models so we can better understand the effects of changes in the physical forcing of the ocean (e.g., small shifts in the location of westerly wind systems may affect ocean processes).
- Biogeochemical Fluxes at the Ocean/Atmosphere Interface. Solar radiation impinging on the oceans creates chemical, physical, and biological effects. One result is the creation of gases, such as carbon dioxide, dimethyl-sulfide, and carbon monoxide, which are then circulated by wind and water. This investigation will develop models to better understand these gases and the influence of oceanic processes upon them.
- Interdisciplinary Studies of the Relationships Between Climate, Ocean Circulation, Biological Processes, and Renewable Marine Resources. This investigation will study (1) the ocean's role in climate change, particularly in the Australian region; (2) the influence of the carbon cycle in Australia's waters on the global carbon cycle; and (3) changes in Australian oceanography and the implications for marine ecosystems, including commercial fisheries.
- The Role of Air-Sea Exchanges and Ocean Circulation in Climate Variability. Exchanges of water, momentum, and heat at the interface of the ocean and atmosphere drive the transport and change the storage of heat, water, and greenhouse gases, thus moderating the world's climate.

This investigation will study these exchanges and ocean circulation in order to improve our understanding of natural global changes and enable us to discern human-induced effects.

- Polar Exchange at the Sea Surface: the Interaction of Ocean, Ice, and Atmosphere. This is an investigation of energy exchanges in Earth's polar regions, both at the atmosphere-ice-ocean interface and lower latitudes. It will study the role these processes play in global oceanic and atmospheric circulation and help improve our understanding of whether polar regions show any sign of climate change.
- Middle and High Latitude Oceanic Variability Study. This investigation will examine the variability of the atmosphere's influence on the oceans, the effect on the oceanic response, and the resulting effect on biological productivity in the oceans. The study will focus on the mid- to high-latitude regions of the oceans. It will examine changes in the surface fluxes of momentum, heat, water, and radiation, as well as the variability of ocean circulation and biological activity.
- Earth System Dynamics: the Determination and Interpretation of the Global Angular Momentum Budget Using EOS. Momentum and mass transport among the atmosphere, oceans, and solid Earth produce changes in the planet's rotation and gravity field. Predictions of these changes based on the mass and motion of air and water can be compared with observations to improve models of the interactions of the oceans, atmosphere, and solid Earth. This investigation will examine these interactions as represented by the exchange of angular momentum, mass, and energy among these components.

The **Chemistry of the Troposphere and Lower Stratosphere** objective includes links to the hydrologic cycle and ecosystems, transformations of greenhouse gases in the atmosphere, and interactions inducing climate change.

- Interannual Variability of the Global Carbon, Energy, and Hydrologic Cycles. Analysis of the carbon, energy, and water cycles may increase the predictability of climate change. The goals of this investigation are to (1) understand contemporary climate variability and trends and (2) contribute to our ability to predict the impact of human activities on the climate.
- Changes in Biogeochemical Cycles. Models of biogeochemical cycles can be used to project the interactions of atmospheric composition, climate, terrestrial and aquatic ecosystems, ocean circulation and sea level, and human-induced effects. This investigation will develop models and

databases to describe the dynamics of water, carbon, nitrogen, and trace gases over seasonal-to-century time scales.

The **Land Surface Hydrology and Ecosystem Processes** objective covers sources and sinks of greenhouse gases, the exchange of moisture and energy between the land surface and atmosphere, and changes in land cover. Investigations in this category could result in improved estimates of runoff over the land surface and into the oceans.

- Global Water Cycle: Extension Across the Earth Sciences. The global water cycle stimulates, regulates, and responds to the other components of the Earth system on regional and global scales. This investigation is aimed at developing a hierarchy of models, using EOS data, that will contribute to our understanding of cloud cover and radiative transfer, as well as energy and moisture changes at the interface of the atmosphere with the oceans, cryosphere, and land surface. These models will contribute to the prediction of changes in water balance and climate.
- Long-Term Monitoring of the Amazon Ecosystems Through EOS: From Patterns to Processes. Natural and human-induced changes in the Amazon are expected to disrupt regional vegetation distributions, alter the physical and chemical characteristics of the continental river system, and change regional hydroclimatology, possibly influencing global climate patterns. The aim of this investigation is to understand the circulation of water, sediment, and nutrients through the basin.
- Northern Biosphere Observation and Modeling Experiment. Natural and human-induced climate changes in the northern latitudes will affect terrestrial ecosystems, and feedbacks from these changing systems will influence the climate. The goal of this study is to better understand the relationship between the climate and northern ecosystems over a range of spatial scales.
- Hydrology, Hydrochemical Modeling, and Remote Sensing in Seasonally Snow-Covered Alpine Drainage Basins. Seasonally snow-covered Alpine regions are important to the hydrologic cycle, as they are a major source of water for runoff, ground water recharge, and agriculture. This investigation will monitor conditions in Alpine basins and develop models to better understand the cycling of water, chemicals, and nutrients in these areas.
- Climate, Erosion, and Tectonics in Mountain Systems. In mountain belts, climatic and tectonic processes produce Earth’s highest rates of weathering and erosion. Alpine regions are important to downstream hydrology, providing both inorganic and organic material to lowland areas. This investigation will observe the effects of climate changes on Alpine

land processes and develop models to improve our understanding of these interactions.

- The Hydrologic Cycle and Climatic Processes in Arid and Semiarid Lands. Knowledge of the hydrologic cycle will help scientists predict the effects of natural and human-induced climate change. This investigation will study the hydrologic cycle and climatic processes in arid and semiarid lands, where agricultural productivity is especially sensitive to changes in the cycle.
- Using Multi-Sensor Data to Model Factors Limiting Carbon Balance in Global Arid and Semiarid Land. This investigation will address the role of arid and semiarid lands in processes affecting the global environment, such as the production and consumption of trace gases. It will also examine the vulnerability of these lands to climate change in terms of productivity and soil quality, and develop predictive models of ecosystem function for dry lands.
- Biosphere-Atmosphere Interactions. This investigation is to improve our understanding of the role of the terrestrial biosphere in global change. It will cover short-term interactions between the land and atmosphere, such as biophysics, as well as long-term interactions, such as ecology and human-induced impacts. The goal of the investigation is to understand and predict the response of the biosphere-atmosphere system to global change, specifically to the increase in atmospheric carbon dioxide.

Glaciers and Polar Ice Sheet measurements could contribute to predictions of sea level and global water balance.

- Use of the Cryospheric System to Monitor Global Change in Canada. The cryosphere is an important component of the global climate system, and better understanding of cryospheric processes may improve global climate models. This investigation seeks to understand cryospheric variations, develop models that will improve our knowledge of the role of the cryosphere in the climate system, and use various cryospheric data sets to support climate monitoring and model development.

The **Chemistry of the Middle and Upper Stratosphere** objective includes chemical reactions, solar-atmosphere relations, and sources and sinks of radiatively important gases.

- Observational and Modeling Studies of Radiative, Chemical, and Dynamical Interactions on the Earth's Atmosphere. Understanding the circulation, transformations, and sources and sinks of gases, such as carbon dioxide, water vapor, ozone, and chlorofluorocarbons, is important in dealing with the issues of global warming, ozone depletion, and the coupling of atmospheric chemistry and climate. This investigation seeks to improve our understanding of the fundamental processes influencing these gases in the atmosphere and contribute to the development of a predictive capability for global change studies.

- Chemical, Dynamical, and Radiative Interactions Through the Middle Atmosphere and Thermosphere. Carbon dioxide and ozone play important radiative roles in the middle atmosphere. Ozone absorbs ultraviolet radiation, heating the middle atmosphere and shielding the biosphere from dangerous ultraviolet dosages. The interactions of other gases, as well as temperature and middle atmosphere circulation, affect ozone. This investigation will improve our understanding of interactions in the middle atmosphere and our ability to predict long-term atmospheric trends.
- Investigation of the Chemical and Dynamical Changes in the Stratosphere. Chemical changes in the atmosphere are occurring largely as a result of changes in the surface emission of trace gases. This investigation will focus on the response of ozone to trace gas changes, isolating natural from human-induced changes to determine their effects on ozone and to assess radiative and dynamical feedbacks.

The **Solid Earth** objective deals with volcanoes and their role in climate change.

- A Global Assessment of Active Volcanism, Volcanic Hazards, and Volcanic Inputs to the Atmosphere from EOS. The injection of material from volcanoes into the atmosphere can affect the local or hemispheric climate. This investigation will improve our understanding of the processes behind volcanic eruptions; study the injection of sulfur dioxide, water vapor, carbon dioxide, and other gases into the atmosphere; and place eruptions into the context of the regional tectonic setting of the volcano.

Comments From the National Aeronautics and Space Administration

Note: GAO comments supplementing those in the report text appear at the end of this appendix.

National Aeronautics and
Space Administration
Office of the Administrator
Washington, DC 20546-0001

MAY 17 1996

Mr. David R. Warren
Director, Defense Management Issues
General Accounting Office
Washington, DC 20548

Dear Mr. Warren:

We have reviewed the GAO's draft report on NASA's Earth Observing System (EOS) (GAO code 709154), which was provided in your letter dated April 17, 1996, to NASA Administrator Daniel S. Goldin. The draft report offered several observations regarding a perceived shortage of NASA-funded scientists to analyze EOS data. The report also recommended that NASA undertake an assessment of the potential effect of the Earth System Science Pathfinder (ESSP) on the Agency's strategy for Earth system science.

See comment 1.

NASA has significant concerns with the fundamental analysis and conclusions in the draft report. Our analysis of the report suggests that GAO should rethink both its reasoning and approach. To contribute to that effort, we have provided an extensive set of specific comments on the report which offer NASA's detailed observations and analysis regarding the issues raised by GAO.

Despite these concerns, NASA agrees with the general intent of the only recommendation and would be pleased to provide a strategic assessment of ESSP to the Congress and GAO. However, NASA plans to proceed with ESSP on the basis of already having carefully analyzed the tradeoffs discussed by GAO and having this approach validated by outside review groups.

If we can be of further assistance, you may call Mr. Douglas Norton or Mr. Mark Pine of the Office of Mission to Planet Earth at 358-0789.

Sincerely,

JR Dailey

J. R. Dailey
Acting Deputy Administrator

Enclosure

NASA Comments on GAO Report "Earth Observing System: Concerns Over NASA's Basic Research Funding Strategy" May 1996

General Comments

See comment 1.

NASA's major concerns regarding the report relate to weak assertions made by the report regarding the number of EOS researchers and their relative ability to handle the amount of data expected from EOS. We feel it is important to provide both a general rebuttal to this assertion, as well as specific arguments directed at the analysis offered by the GAO in support of their position. Our comments fall into several areas (listed below), which are explained in greater detail in the subsequent pages:

- The GAO seriously underestimates the number of researchers likely to use EOS data by omitting *thousands of researchers* who are funded by other programs, agencies, and nations.
- Regular feedback from EOS investigators makes NASA confident they are fully aware of how much data will need analysis and are capable of delivering the derived science products.
- Simple data rate comparisons, such as those in the GAO report, are misleading and fail to acknowledge substantial differences in the way different types of data are analyzed and used to generate useful products.
- Despite GAO's concerns, NASA researchers are already routinely generating results from data volumes comparable to those expected from EOS satellites.
- GAO's analysis ignored both past and expected rapid advances in capabilities for processing and analyzing data and the fact that these advances are being (and will be) continuously incorporated into the EOS data system.
- GAO overlooked extensive NASA efforts to ensure that EOS researchers had the necessary tools (i.e., computing capabilities, visualization methods, data assimilation techniques) to benefit from the rich information content of EOS observations.

See comment 1.

Specific Comments

"The size of the EOS basic research community is small..." (page 6, top paragraph)

NASA Comment: NASA believes that the GAO has seriously underestimated the number of researchers likely to use EOS data by omitting *thousands of researchers* who are funded by NASA programs other than EOS, other agencies, and other nations. Because the EOS data policy requires broad and timely availability of all EOS data, all such researchers will be able to conveniently access EOS data to support their research. The GAO asserts that the only researchers who will analyze EOS data are those directly funded by NASA's EOS program for that purpose. This assumption drives most of the conclusions in GAO's report, and NASA believes it suffers from several key deficiencies.

First, this ignores the more than 1100 researchers from 45 states also funded by the Mission to Planet Earth Research and Analysis (R&A) program, a level which is likely to be fairly steady in the future. As EOS data become available, a large number of these researchers will utilize the data for their disciplinary studies. NASA has strengthened the links between the science content of the R&A program and that of EOS, and the draft MTPE Science Research Plan attempts to describe these links in terms of priorities and requirements. Each of the five priority areas identified in the plan require analyses using data from EOS, other satellites, and in situ observations. While EOS and R&A researchers may approach the five science priorities from slightly different vantage points (and with different specific objectives), their research is intended to be compatible and interactive.

Second, an additional pool of EOS data users will be the thousands of researchers who are supported by other Federal agencies through the U. S. Global Change Research Program (USGCRP). Many of their investigations specifically depend on the existence of EOS data. Similarly, many of the observations planned for EOS were designed to supply data that would be essential for research being funded by other USGCRP agencies. There is a wide range of financial supporters for the Earth system science community, including other U.S. Government agencies, the international community (ESA, Japan, Canada, etc.), and non-government organizations.

Third, NASA established a graduate student fellowship program in 1990 to support education and training of the next generation of scientists to support the EOS and MTPE programs. Each year NASA makes fellowship awards to 50 additional students who are pursuing their doctoral degrees and focusing on interdisciplinary research in Earth system science. More than 300 fellowships have been awarded in the 6 years since the program began.

Finally, none of these discussions addresses the much larger community of users who will access EOS data for numerous other applications. While these users may not be scientists, their work will advance our understanding of specific data applications, providing critical insight that could help focus aspects of scientific research and planning. Landsat currently serves a broad constituency and the emerging commercial sector illustrates the expectation for future growth.

"...based on comparisons of (1) the number of science teams associated with the two pre-EOS missions -- the Upper Atmosphere Research Satellite (UARS) and the U.S.-French Oceanography Satellite (TOPEX/POSEIDON) -- to their EOS-era counterparts..." (page 6, first paragraph)

See comment 2.

NASA Comment: A simple comparison of the number of teams working on the respective missions is very misleading.

First, the pre-EOS and EOS science teams are doing different things. The science teams selected for the EOS missions have the sole responsibility of developing the algorithms (computer codes developed to make raw data meaningful) and conducting the initial processing of the data necessary for its analysis by the rest of the scientific community (consistent with the open EOS data policy, which is designed to make data widely available as quickly as possible). By contrast, the original UARS and TOPEX science teams (excluding the more recently selected guest investigators) had both this task and the *exclusive analytical rights* to their data for the early periods of both missions (24 months for UARS; 12 months for TOPEX/POSEIDON). Because of this significantly increased level of analytical responsibility, it is not surprising that there would be relatively more investigators (and teams) for UARS and TOPEX/POSEIDON than for EOS.

Second, taking this fact into account, GAO's assertion ignores the breadth of scientific interest in EOS measurements relative to those from UARS and TOPEX/POSEIDON. EOS spacecraft will measure a broad range of variables, and will foster both disciplinary and interdisciplinary analyses. As noted above, the likely universe of potential science users for EOS data is in the thousands. By contrast, UARS and TOPEX/POSEIDON both had fairly narrow scientific foci, which suggests that the community of researchers likely to analyze that data would be much smaller; as a consequence, NASA made a decision to support a relatively larger number of teams to ensure that data received the necessary attention.

"...and (2) the ratio of the number of science teams to the raw data acquisition rate expected from instruments on EOS spacecraft to the number of science teams and raw data acquisition rates of UARS and TOPEX." (page 6, first paragraph)

See comment 3.

NASA Comment: NASA believes that GAO has missed several critical points in performing its analysis on this topic. NASA representatives expressed this concern several times to the GAO investigators and offered a number of arguments relative to the likely findings.

Current Investigators Do Not Share GAO Concerns. As the report notes, EOS investigators affirmed in 1992-93 and 1995 that program funding levels and design (accounting for numerous budget reductions and program restructurings) would not "weaken their ability to conduct interdisciplinary research." As the GAO stated in the report: "Most investigators reported that the changes had so far created only minor problems that could be adequately resolved. A NASA official told us that a reason for investigator's optimism is that NASA officials consciously tried to minimize the impact of budget reductions on EOS-related science."

All EOS investigators have been aware of the volumes of data planned for the program since they originally submitted their research proposals in 1989, and all signed agreements with NASA to meet those obligations. NASA has held regular meetings of the investigators to ensure that all necessary steps were being taken to ensure that investigators received needed support. Furthermore, since the selections of those research proposals in 1990, *the number of unique EOS data products has declined by 75 percent and the data rate from the planned EOS satellites has been cut by more than half.* At the same time (as noted above and in the GAO report), the number of EOS investigators is increasing. In 1995, NASA released a NASA Research Announcement seeking additional investigators for the EOS program and expects to add *200-250 researchers* to the current EOS complement of 533 *researchers* when selections are made this summer. Many of the current EOS investigators support post-docs, research associates, and computer programmers as part of their funded investigation, so the number of scientists focused on developing algorithms, models, and visualization tools far exceeds the formal number of EOS investigators. Additional solicitations for specific research areas of EOS science are also planned for the next several years.

Simple Numerical Comparisons of Data Rates Are Misleading. In the report (and preceding congressional testimony), several references are made to comparisons of the average data rate per investigator and number of science teams (and investigators) for current missions relative to the number for their EOS equivalents. One notable comparison was between the Upper Atmosphere Research Satellite (UARS) and the analog EOS mission, EOS-Chemistry (EOS-CHEM). In an effort to make its own "apples to apples" comparison, NASA performed an analysis of the data rate per investigator for UARS compared with EOS-CHEM. This comparison revealed that each EOS investigator would be expected to handle, on average, about 100 times as much basic data as those for UARS. The reason for conducting such a comparison was to test the reasonableness of the GAO premise: that there is a direct relationship between data volume and the number of researchers required. NASA's analysis suggests several fundamental flaws in this assumption.

First, as noted above, the members of the teams are doing different things.

Second, data products are much more important than data volumes. In other words, though all data are not the same, they can be processed/analyzed to produce similar products. For example, the Tropospheric Emission Spectrometer (TES) instrument on the CHEM mission is an interferometer, a very sensitive, high-spectral resolution device used to make very precise and difficult atmospheric measurements (e.g., it tries to detect relatively small amounts of ozone in the upper troposphere while having to look through the much more abundant quantities of ozone in the stratosphere). Though TES produces a very large stream of data relative to any of the instruments on UARS, the final data products that result from its observations are of the same general character (indeed, the end result of the TES data reduction will be atmospheric constituent concentrations as a function of altitude and location, just as for UARS). The key to the number of researchers required for value-added analysis is <u>not</u> the amount of data originally obtained, but the resulting products and the process which leads to that result. Whether one applies an algorithm to 1 million or 1 billion pixels in a day does not affect the complexity of the algorithm, change the character of the resulting data product, or increase the number of researchers required to produce the product. In this manner, the factor of 100 increase from UARS to CHEM only seems significant until one realizes there is a factor of 1000 increase in the data content of a commercial radio station compared to a commercial TV station— with dramatic improvement in data comprehension. The same user is getting a richer display of the information sought, not necessarily a larger amount of the same kind of data.

Third, different types of instruments produce fundamentally different types (and rates) of data. Especially with the addition of Landsat to the EOS program, the quantity of imagery data in EOS dwarfs most other elements of the program. Imaging instruments (as noted in a footnote on page 6 of the report) tend to produce fundamentally higher data volumes (and therefore rates) than non-imagers (such as those on UARS and TOPEX/POSEIDON). As with TES, however, the key is how the data are best analyzed. Techniques and technologies for imaging instruments are generally designed to handle a larger data flow as part of their processing. It takes a lot of imagery data (in terms of bytes) to produce a single meaningful image that could be used in scientific analysis. Doing a simple comparison of data rates per investigator can significantly distort an assessment of how much data is "too much." For example, the data rate per investigator for the Landsat-7 Enhanced Thematic Mapper (planned for launch in 1998) is expected to be *25 to 40 times* that for the MODIS instrument on EOS AM-1 (also planned for 1998 launch). However, scientific and applications users of existing Landsat data have been regularly generating analyses and results for years, indicating that the amount of data produced by the Landsat program is not overwhelming researchers. These users have developed tools to enable them to process the data into useful products. EOS researchers are using those types of experiences to build the algorithms and other tools for analyzing the large quantities of EOS data.

Fourth, all data are not intended to be analyzed in the same way or at the same time. Of the total data collected by an instrument and transmitted back to Earth, only a portion may actually have immediate need for analysis. Some of the data may be most useful for refining the measurements made by other instruments, while other data might be of a portion of the spectrum or an area of the Earth that is of lower research interest. Some datasets will become useful only after a significant amount of data is collected (e.g., when there is enough data to indicate a trend). As with analyses of data today, researchers will not be looking at every data item with the same fidelity. Moreover, there are very few data from space, either today or planned for the EOS era, that investigators will need (or want) to analyze in real time (i.e., where the data come down from orbit, go to a processing/archiving center, and are immediately disseminated to researchers for analysis). Rather, most investigators will order data from the archive or processing center and then analyze the time series for the region in which they have an interest (up to and including the entire globe). This changes the real issue from one of rapid throughput (i.e., data rate per investigator) to one of sufficient storage of data at both the archive/processing center, and then sufficient storage and investigative capability at the investigator's institution. NASA has been working closely with EOS researchers to address both of these challenges.

NASA Scientists Are Already Working Successfully With Large Data Volumes. As part of the planning for EOS, NASA established a data pathfinder program that takes advantage of remotely sensed space-based observations acquired by the NOAA polar orbiting and geosynchronous satellites, the Defense Meteorological Satellite Program (DMSP), and Landsat satellites. Individual scientists have the capabilities at their institution today to receive data directly from some of these satellites, and to process and analyze the data and distribute it to other potential users. The 1993 Amazon deforestation study was conducted by two scientists (one each from Universities of Maryland and New Hampshire) who acquired and processed 1500 Landsat scenes (i.e., each Landsat scene is 160 km x 180 km in area and constitutes hundreds of megabytes of data). Scientists from the University of Alabama, Huntsville, are assembling the largest and longest atmospheric temperature records obtained by civilian weather satellites and are routinely distributing the data to other users. Scientists from the University of Hawaii have built a satellite data receiving station that is capable of collecting data routinely from European and Japanese satellites and distributing it to the rest of the national and international user community. Studies are underway to examine deforestation in Asia and droughts and desertification in Africa and Asia, based on at least 10 years of data from Landsat and NOAA satellites as well as long-term records of data acquired by ground-based networks. *In each of these examples*, the volumes of data being used are approaching the gigabyte and terabyte range -- which is consistent with the quantity of data expected from EOS -- and the analysis of that data is based on the use of *current technologies*.

Capabilities For Analyzing Data Are Rapidly Advancing. One of the main flaws of simple numerical comparisons is the failure to incorporate the rapid changes in analytical tools. For example, the numerical comparisons between UARS and EOS-CHEM above fail to account for more than a decade of data management technology advancements that will be available to EOS-CHEM researchers when the satellite is launched in 2002. Advances in technology over the last decade alone -- in areas like memory capacity, processing time and throughput, and network performance -- suggest that capability will improve during the next decade by factors of 10, 20, and even 100.

"Data richness" is being built into the EOS program as a **requirement** for interdisciplinary research in Earth system science. Many of the interdisciplinary research activities that will draw from the program require observations from multiple instruments and will use refined data subsets (Level 3 or 4 products) for their analysis, which provide to the user a smaller actual databyte reservoir to work with (though each of these products are generated by the higher information content of the original data streams). The challenge is converting the original high-content streams into comprehensible products which can allow the analyst to identify the unusual events which warrant a return to the original source data. Thus, the objective is to develop the necessary algorithms, models, and visualization tools well in advance of the launch of the instruments; NASA has numerous efforts underway to ensure that this occurs.

As with other aspects of information technology, visualization technology has been advancing at a rapid rate in the last decade and such advances are only expected to increase in coming years. One example of this advance in technology is the Interactive Image Spreadsheet (IISS) currently used by GSFC in some of its visualization activities. The IISS is designed specifically to process large quantities (gigabytes and more) of multispectral data collected over long periods of time. The IISS enables rapid browsing and takes advantage of state-of-the-art Internet-connected computer systems. Current projections are that, in a few years, improvements in personal computer performance and reductions in cost will make the capabilities of the IISS and other high capacity tools available to the vast majority of Earth scientists.

NASA Is Ensuring That EOS Investigators Have Needed Support. Two important aspects of EOSDIS development are designed specifically to ensure that the EOS investigators have the resources necessary to analyze the data. First, NASA has upgraded computing capabilities for the EOS investigators to better handle large data flows and analyses. By the first EOS launch in 1998, NASA will have spent in excess of $150 million on computing capabilities for the EOS investigators. Second, NASA has invested millions more in browse, visualization, and data archiving technology and has made a commitment in its program planning to ensure that the latest technology is seamlessly and continuously incorporated into the program. Both these efforts have been underway since the inception of the EOS program.

"We recognize that a science team/data rate ratio is, at best, a rough gauge of the magnitude of the data analysis opportunities facing the Earth science research community. However, the difference is too large to ignore, especially when viewed together with significant disparities discussed above in the number of science teams for comparable pre-EOS and EOS-era instruments." (page 8, first full paragraph)

See comment 1.

NASA Comment: As noted above, analysis based on simple, static comparisons of teams and data rates is fundamentally misleading, especially absent the context for the larger research community which is certain to use EOS data in performing basic research. The "disparities" noted by GAO fail to justify their assertions regarding the relative size of the EOS research community; instead, such disparities are usually used by analysts to identify areas that merit further, more detailed, and more comprehensive analysis. In this instance, GAO has failed to follow through on that analysis.

See comment 4.

"Actually, the fact that 10,000 Earth scientists may be potential users of EOS data overlooks the requirement that scientists still need to be funded to conduct basic research on global climate change. We found that for this type of work, scientists analyze data when they are paid to do so." (page 10, first paragraph)

See comment 5.

NASA Comment: NASA believes that there is basis for a vigorous debate on the assertion regarding the fact that scientists (and others) would analyze data only when funded to do so. However, the larger issue here is clearly that GAO has dramatically underestimated the federally funded basic research user community for EOS data. By ignoring NASA's R&A investigators and those funded by other Federal agencies (not to mention those from the international community), GAO fails to acknowledge the broad base of non-EOS scientists who will certainly use EOS data.

See comment 1.

"Our review of the authorship of 172 journal articles about 2 pre-EOS-era satellites - UARS and TOPEX/Poseidon - showed that publicly funded investigators wrote all but 10 of the articles." (page 10, second paragraph)

See comment 1.

NASA Comment: Again, even if one accepts the premise that only federally funded researchers will use EOS data, this point is only relevant if one assumes that the only publicly-funded researchers that will use EOS data are EOS interdisciplinary researchers, an assertion that is clearly not borne out by the evidence discussed above. Moreover, it is not particularly surprising that UARS and TOPEX investigators authored most of the papers on data from those two satellites, since both sets of researchers had exclusive access to the data for 12 to 24 months after data began to flow. At the time of GAO's literature search, UARS had been in orbit for about 36 months, while TOPEX/Poseidon had been in orbit for about 29 months.

"Although NASA has not determined what size research community is sufficient to meet EOS' basic research goals, it does recognize that more basic research teams are needed and took a limited step last year to add more." (page 12, top paragraph)

See comment 6.

NASA Comment: As the report notes, NASA is in the process of adding additional investigators as the first EOS launch nears. When selections are announced later this summer (in response to the NASA Research Announcement released in fall 1995), we expect to increase the total number of EOS researchers by 200 to 250 (an increase of at least 35 percent). NASA does not consider this to be a "limited" step. Moreover, NASA undertook this action for a number of reasons apart from a desire to simply expand the size of the direct EOS research community. As stated in the NRA, we were seeking membership for new science teams, additional investigators to help address new science areas and to bring new ideas to bear, and young investigators seeking to establish themselves in the Earth system science research community.

"While potentially useful over the longer term, these grants will not immediately increase the size of the EOS research community conducting basic research in the near term..." (page 12, third paragraph)

See comment 7.

NASA Comment: Again, this is only a problem if one believes that the near term community of researchers is too small. NASA profoundly disagrees with this assertion, and notes that GAO has failed to offer any substantive evidence in support of its claims. Moreover, contrary to GAO's statement in the report, NASA is not limiting the focus of the new researchers to pre-EOS missions. When EOS data is available in 1998, they will certainly make use of it to the extent that it supports their specific research objectives.

"The review by EOS investigators' peers in the Earth sciences research community is not yet finished, but it could lead to the possible deselection and recompetition of some EOS interdisciplinary science teams." (page 13, first paragraph)

See comment 8.

NASA Comment: The report notes the results of a 1992-93 review of the performance of EOS interdisciplinary science teams, but fails to mention steps that NASA took after that review to improve team performance and planning. One of those steps was to conduct peer reviews of the science teams, which is moving toward completion. It is important to note that the primary criticisms cited by the 1992-93 review related to the management of team activities, not the quality of science being undertaken or the ability of the researchers to manage large quantities of data in the EOS era.

"However, NASA has not demonstrated that the potential value of Pathfinder's science would exceed the potential value of additional EOS-related science, if savings allocated to Pathfinder were allocated to EOS science." (page 18, first paragraph)

NASA Comment: The Earth System Science Pathfinder (ESSP) is a science-driven program intended to identify and develop small satellite missions (using state-of-the-art technology) to accomplish scientific objectives in response to national and international research priorities that are not being addressed by current programs (such as EOS). ESSP will provide periodic "windows of opportunity" to accommodate new scientific priorities and infuse new scientific participation into the Mission to Planet Earth program. By launching ESSP missions on a frequent, regular basis, NASA will provide a mechanism by which pressing questions in Earth system science may be addressed in a timely fashion, permitting a continual improvement in our understanding of the Earth system and the processes that affect it. In doing so, it will also provide researchers with an opportunity to work on missions that have much shorter time horizons (for development and flight) and thus to broaden participation by the science community in such missions. A portion of the spending for each ESSP mission will be used to select and fund a science team focused directly on the science of that mission.

NASA has reviewed the concept and approach for ESSP with a number of external science groups, including the National Academy of Sciences Board on Sustainable Development. Many of those groups have been the same ones urging NASA to create such a responsive program to address emerging science questions beyond the 24 core measurements that are a part of EOS. Their concern, recognizing the critical importance of the 15-year data set to be acquired by EOS, is that without a program like ESSP, the opportunities for NASA to introduce new science into Mission to Planet Earth would be limited. EOS researchers, in particular, have been supportive of ESSP.

NASA has always worked with the science community to establish an appropriate balance between the conduct of existing programs and the initiation of new ones. In planning ESSP, NASA carefully assessed the balance in planned spending between ESSP, EOS, and other programs. During the most recent EOS reshaping activity in 1995, a near-term and outyear wedge of funding was developed from within the EOS program (mostly from savings in flight and data system activities) to fund the initiation of ESSP and the Earth science portion of the New Millennium Program. NASA also thought ESSP was such a high priority that additional funds for ESSP were allocated from programs outside of Mission to Planet Earth.

NASA is confident that the community of researchers who will analyze EOS data--both those funded directly for that purpose and the larger community of scientists--is up to the task. Research announcements planned over the course of the next several years will help to bolster and refresh that community. At the same time, NASA is convinced of the wisdom and value of proceeding with ESSP. A draft solicitation for the first mission was released earlier this year and generated substantial interest. NASA feels that ESSP is responsive to the repeated requests from the scientific community and represents a sound investment for our Nation.

Other NASA Comments

See comment 9.

Page 2, top paragraph. In terms of the relative amount of funds involved, we suggest switching the order in last sentence to read as follows: "NASA intended to use these future savings to reduce the total cost of EOS and Mission to Planet Earth and to fund emerging science areas not currently covered within the program." The vast majority of savings from the infusion of new technology and collaborations will be used to reduce overall outyear program costs (particularly in EOS); thus, in order of relative importance, this clause should be listed first.

See comment 10.

Page 3, second paragraph. The current planned spending for EOS through 2000 is estimated at approximately $6.8 billion, not $7.25 billion.

See comment 11.

Page 4, first paragraph. NASA continues to disagree that "the viability of this plan [regarding savings to EOS costs from 'improved technology and increased collaboration'] is uncertain." NASA has already made changes to the program baseline that will result in a significantly lower runout cost than that cited by GAO in their 1995 report on EOS costs. Moreover, our close interactions with the commercial community have convinced us that further innovations--in spacecraft, instrument, subsystem, and information system technologies--will both enable us to decrease costs further and improve the capability of the overall system, all while maintaining critical data continuity. Consequently, we also strongly disagree with GAO's assertion that "there may be a growing imbalance between the number of funded investigations and the magnitude of the potential research opportunities created by data from EOS' instruments." We believe GAO has failed to offer sufficient evidence or analysis to justify this assertion.

See comment 12.

Page 11, second paragraph. The comments by "a senior NASA official" add virtually nothing to this argument and appear as little more than hearsay if a source cannot be cited to produce a full quote. Failing that, we recommend dropping this reference.

The following are GAO's comments on NASA's letter dated May 17, 1996.

GAO Comments

1. Refer to the "agency comments and our evaluation" section of the report.

2. Our analytic framework was not designed to assess the science teams' ability to do the tasks they are currently funded to do. In its comments, NASA points out that the breadth of scientific interest in EOS measurements is likely to be greater than the interest in Upper Atmosphere Research Satellite (UARS) and Ocean Topography Experiment (TOPEX) measurements. This view is consistent with our observation that the scientific opportunities afforded by EOS are likely to be greater than those afforded by these pre-EOS-era missions. The difference in potential research opportunities afforded by EOS and, for example, UARS and TOPEX is illustrated by the differences in the number of investigations and data rates of EOS and these two pre-EOS-era missions. NASA's strategy is to begin increasing the number of EOS investigations.

3. We met with NASA personnel at various times throughout our fieldwork and considered their views in preparing our draft report. In this section of its comments, NASA notes a number of issues related to its interpretation that our draft report was intended to estimate the potential EOS user community and to assess the ability of current EOS researchers to process the large amounts of data expected from EOS. We have made changes in the final report to clarify our objectives. As an example of NASA's misinterpretation, it specifically criticizes our data rate comparison, presents a comparison of its own, and expresses its confidence that this difference (EOS CHEM mission investigators must handle 100 times more data than UARS investigators) is not significant. Again, we did not assess the ability of investigators to handle data. Also, we did not discuss the "average data rate per investigator," as stated by NASA. Further, our use of data rates is consistent with the way NASA used them in its 1993 and 1995 editions of the EOS Reference Handbook—namely, to help illustrate the magnitude of science opportunities afforded by EOS compared to pre-EOS-era Earth observing missions.

4. Our comparisons, coupled with NASA's efforts to begin increasing the number of EOS investigations, support the need to assess what is necessary and sufficient EOS basic research. As NASA stated, this question merits "further, more detailed, and more comprehensive analysis." The recommendation to NASA in our draft report was intended to ensure that

this question is at least addressed in the context of Pathfinder. In our judgment, the matter for congressional consideration has the same intention.

5. The observation that “scientists analyze data when they are paid to do so” was made by several senior NASA officials. Our analysis of the authorship of UARS and TOPEX journal articles was to verify these officials’ observation.

6. Our use of the term “limited” was not referring to the number of investigations NASA hopes to add. Rather, it refers to the fact that newly selected interdisciplinary science investigators will be largely precluded from analyzing data from the first EOS mission. We have clarified the report.

7. We did not say the near-term community of researchers is “too small.” We said the number of currently funded EOS science investigations is small compared with two pre-EOS-era missions and the potential research opportunities afforded by EOS. Senior NASA officials told us that budget constraints slowed their efforts to increase the number of EOS investigations. In September 1995, NASA began its formal efforts to add more investigations because it had created sufficient “savings” to fund them. We did not say, as NASA contends, that it is limiting the “focus” of newly selected investigations to pre-EOS-era missions. Rather, we said that the new investigators would be largely precluded from analyzing data from the first EOS mission, based on the following language from the September 1995 announcement:

> Investigations to begin in 1996 cannot depend solely on data from EOS instruments because the earliest launch dates are planned for 1997 (for [Tropical Rainfall Measuring Mission]) and 1998 (for EOS-AM-1). Instead, research plans should be based on use of existing data sets . . . or expected data from relevant near-term (1996-1997) satellite missions and field experiments.

8. Our draft report discussed the 1995-96 peer review, noting that the review could lead to possible deselection and recompetition of some EOS science teams.

9. We incorporated the amount of funds involved in the program into the report’s text.

10. We included NASA's current estimate of planned EOS spending through fiscal year 2000 in the report's text.

11. We revised our report to include NASA's comments about lower program baseline costs and its confidence that it will decrease costs further.

12. We deleted the material NASA is referring to.

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