NASA EARTH SCIENCE

HEARING

BEFORE THE

COMMITTEE ON SCIENCE
HOUSE OF REPRESENTATIVES

ONE HUNDRED NINTH CONGRESS

FIRST SESSION

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C O N T E N T S

April 28, 2005

Appendix 1: Answers to Post-Hearing Questions

Appendix 2: Additional Material for the Record

NASA EARTH SCIENCE

THURSDAY, APRIL 28, 2005

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE,
Washington, DC.

The Committee met, pursuant to call, at 10:00 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Sherwood L. Boehlert [Chairman of the Committee] presiding.

COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES
WASHINGTON, DC 20515

Hearing on

NASA Earth Science

April 28, 2005
10:00 a.m. – 12:00 p.m.
2318 Rayburn House Office Building

WITNESS LIST

Mr. Alphonso Diaz
Associate Administrator
Science Directorate
NASA

Dr. Berrien Moore III
Director
Institute for the Study of Earth, Oceans, and Space
University of New Hampshire

Dr. Tim Killeen
Director
National Center for Atmospheric Research

Dr. Sean Solomon
Director
Department of Terrestrial Magnetism
Carnegie Institution of Washington

Dr. Marcia McNutt
President and CEO
Monterey Bay Aquarium Research Institute

Dr. Ray Williamson
Research Professor
Space Policy Institute
The George Washington University

HEARING CHARTER

COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

NASA Earth Science

THURSDAY, APRIL 28, 2005
10:00 A.M.–12:00 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING

Purpose

On Thursday, April 28, at 10:00am, the Committee on Science will hold a hearing to examine the state of Earth science programs of the National Aeronautics and Space Administration (NASA).

NASA proposes to spend about $1.37 billion on Earth science research in Fiscal Year (FY) 2006, a cut of about $120 million, or eight percent, from FY 2005 (or about $180 million, or 12 percent, below the FY04 request).

In a report to be released this week, the National Academy of Sciences concludes that the budget cutbacks threaten the vitality of NASA's Earth science research, as many Earth science missions have been downsized, delayed or canceled. The report is part of the "Decadal Survey" being conducted by the Academy at NASA's request to help the Agency set priorities in the Earth sciences. The final report is due in late 2006.

The primary activities of NASA's Earth science program are to develop and launch research satellites designed to improve understanding of the land, oceans and atmosphere. In the past, NASA missions have helped gain new knowledge and create new capabilities that have led to advances in weather forecasting, storm warnings, and the ability to more efficiently manage agricultural and natural resources.

But the National Academy of Sciences report warns that U.S. leadership in developing such capabilities is threatened by the drop in support for NASA's Earth science research. Because at the time of this writing the report has yet to be released, NASA has not issued a response.

NASA's new Administrator, Michael Griffin, in his public statements has expressed general support for Earth science at NASA.

Overarching Questions

The Committee plans to explore the following overarching questions at the hearing:

1. What is NASA's long-term strategic vision for conducting Earth science observations from space? How does the current budget reflect that vision?
2. What are or what should be the top priority missions for Earth science? How would these priorities benefit society?
3. What are the implications of NASA's recent actions to cancel or reduce funding for several Earth science missions? How would the proposed cuts affect interagency programs such as those on climate science and Earth observations?

Witnesses

Alphonso Diaz is the Associate Administrator at NASA for the Science Mission Directorate, which includes Earth sciences.

Dr. Berrien Moore is the Co-Chairman the National Academy of Sciences Decadal Survey, "Earth Observations from Space: A Community Assessment and Strategy for the Future." Dr. Moore is also the Director for the Institute for the Study of Earth, Oceans, and Space at the University of New Hampshire.

Dr. Tim Killeen is the Director of the National Center for Atmospheric Research in Boulder, Colorado.

Dr. Marcia McNutt is the President and Chief Executive Officer of the Monterey Bay Aquarium Research Institute in Moss Landing, California.

Dr. Sean Solomon is the Director of the Department of Terrestrial Magnetism at the Carnegie Institution of Washington.

Dr. Ray Williamson is a Research Professor in the Space Policy Institute at The George Washington University.

Background

Recent Developments: National Academy Report

At NASA's request, the National Academy of Sciences (NAS) Committee on Earth Science Applications from Space is currently conducting a "Decadal Survey" for Earth science observations from space. Similar to the decadal surveys conducted with great success in astronomy and the planetary sciences, the Earth science decadal survey is expected to establish a prioritized list of research projects that the entire Earth sciences community agrees should be funded for the next ten years.

This will be the first time a decadal survey has been conducted for Earth science. It is a challenging undertaking because the field is broader and deals with more federal agencies than astronomy does. The NAS Committee Chair, Dr. Berrien Moore, will be testifying at the hearing.

The NAS Committee this week is releasing an interim report titled "Earth Science and Applications from Space: Urgent Needs and Opportunities to Serve the Nation." The report states that "recent changes in federal support for Earth observation programs are alarming." The report's Executive Summary states:

> At NASA, the vitality of Earth science and application programs has been placed at substantial risk by a rapidly shrinking budget that no longer supports already approved missions and programs of high scientific and societal relevance. Opportunities to discover new knowledge about the Earth are diminished as mission after mission is canceled, de-scoped, or delayed, because of budget cutbacks, which appear to be largely the result of new obligations to support flight programs that are part of the Administration's vision for space exploration.

The NAS Committee specifically recommends that NASA launch on schedule two Earth science missions that have been threatened with delays or cancellations. It also recommends that NASA request brief studies of its plans for three other missions. NASA has said that those missions could be launched on board the NPOESS satellite rather than as independent missions. (NPOESS stands for National Polar-orbiting Operational Environmental Satellite System and is being launched by the National Oceanic and Atmospheric Administration (NOAA) and the Department of Defense.) Finally, the NAS Committee recommends that NASA "re-invigorate" several smaller Earth science programs. (The Executive Summary of the NAS report is attached, and more information on specific missions is included below.)

Earth Sciences

NASA's mission statement begins with the goal, "To understand and protect our home planet." NASA research in Earth science has thus focused on understanding how the Earth's atmosphere, oceans, and land interact and operate as a whole, with an eye toward direct societal applications.

Within the Earth sciences program, one of NASA's primary roles is to build and launch research satellites to provide a deeper understanding of the basic processes governing the Earth's physical system. Capabilities and discoveries from NASA's program are often later incorporated by other agencies into the satellites they use in their ongoing operational programs, such as weather or geographic imaging satellites.

One example of how the NASA program works and contributes to operational programs is its Tropical Rainfall Measuring Mission (TRMM), which NASA launched in 1997 and is now scheduled to end operations this summer. TRMM provides data that was never before available on tropical precipitation patterns to help scientists study the water cycle and related issues including climate change. But unexpectedly, TRMM has also given researchers new insights into determining the track and intensity of hurricanes, which could contribute to future efforts to predict the landfall of hurricanes, which is the responsibility of NOAA. NOAA could place instruments based on TRMM on future weather satellites.

The Global Precipitation Mission (GPM), the planned follow-on mission to TRMM, would continue to provide further improvements in the observation of rainfall by, among other things, expanding rainfall information to the entire globe. NASA has delayed the launch of GPM several times. (See below.)

In another example, NASA researchers are also exploring whether data from Earth observing satellites can be used to track ocean pollution from runoff. (See attached article from *Space News*).

NASA satellites have made substantial contribution to a variety of areas, such as documenting the existence of a hole in the ozone layer in the upper atmosphere. Future NASA missions could potentially provide useful information for a number of important societal needs. For example, interferometric synthetic aperture radar (InSAR) technology that some scientists have suggested for a future NASA mission could be able to detect small changes in surface of Earth to presage volcanic eruptions or landslides. Also, NASA's Glory mission, which has recently been downscaled (see below), was developed to help resolve one of the largest uncertainties in scientists' understanding of climate change, the effects of the variable output of the sun and of atmospheric aerosols (black soot and carbon).

NASA's Goddard Space Flight Center (MD), Jet Propulsion Lab (CA), and Ames Research Center (CA) each contribute substantially to Earth sciences research at NASA.

NASA Earth Sciences Budget

Funding for the Earth sciences has declined each year since FY 2004, and the President's FY 2006 budget submission continues this reduction. The table below compares the last three budget requests (including the accompanying run-out for the four following years) for NASA's Earth science programs:

NASA Earth Science Funding ($=Billions)

	FY2004	FY2005	FY2006	FY2007	FY2008	FY2009	FY2010
2004 Request	**1.55**	1.53	1.6	1.7	1.73		
2005 Request		**1.49**	1.39	1.37	1.34	1.47	
2006 Request			**1.37**	1.35	1.33	1.47	1.44

The budget for the Earth sciences programs at NASA was cut sharply in FY 2005, with reductions in the run-out for the years 2005–2009 totaling over $1 billion as compared to the planned budget for these years at the time of the FY 2004 budget submission. The FY 2006 budget request reduces this amount slightly further.

In the FY 2006 budget request, NASA has made it difficult to determine Earth science funding by consolidating the Earth science programs and several space science programs into a new "Earth-Sun System" theme within the new Science Mission Directorate. (Earth sciences had previously been a separate directorate from space sciences. The Science Committee was able to get the Earth science figures only after repeated requests.) The Earth-Sun theme also includes the "Sun-Earth Connections" programs, such as the Voyager mission, which continues to send back data from the outer limits of the solar system. The funding table above includes only funding for Earth sciences. For information regarding funding for the entire Earth-Sun System theme as a whole see Appendix B.

Effect of Budget Reductions

The budget reductions have led NASA to delay, cancel or scale back most Earth science missions. Furthermore, NASA has few if any additional Earth science missions in the planning pipeline beyond the missions that have been in the works for years. Also, NASA does not appear to have sufficient funds to launch some of the missions that it describes as being on schedule.

For example, the NASA Global Precipitation Measurement (GPM) satellite, which is to be coordinated with launches of related satellites by other nations, was first scheduled to be launched in 2007. Currently, launching in 2010 would be considered "on schedule." In its FY 2005 budget request, NASA delayed the launch until 2012. In the FY 2006 request, the date has been shifted back to 2010, but it is unclear whether NASA has requested sufficient funding to make that date.

The NAS Committee interim report recommends that the GPM mission be launched without further delays, citing its international nature and the importance of understanding "the availability of fresh water."

Another mission affected by the budget cutbacks is Glory, which is designed to study one of the highest priority questions in climate change science. Glory was originally intended to fly as a stand-alone mission in 2008. But in 2005, NASA began talking instead about just building the instruments for Glory and then looking to see if they could be launched on another satellite, such as NPOESS. NASA has not been able to say when or even if Glory would be able to be launched if it "piggy-backed" on another mission. Under pressure from the Science Committee and the House Appropriations Committee, NASA has extended the contract to build a launch vehicle for an independent Glory mission, but the future of the mission is still in doubt.

The NAS Committee interim report recommends that NASA commission an independent review to determine the "suitability, capability and timeliness" of placing the Glory instruments on another satellite.

The table below summarizes the status of all of NASA's currently planned large Earth science missions:

(Adapted from TABLE 3.1 from the NAS report: "Cancelled, De-scoped, or Delayed Earth Observation Missions)

Mission	Measurement	Societal Benefit	Current status
Global Precipitation Measurement (GPM) mission	Precipitation	Reduce vulnerability to floods and droughts; manage water resources in arid regions; improve forecasts of hurricanes	Unclear
Atmospheric Soundings from Geostationary Orbit (GIFTS)	Temperature and water vapor	Protect life and property through improved weather forecasts and severe storm warnings	Cancelled
Ocean Vector Winds	Wind speed and direction near the ocean surface	Improve severe weather warnings to ships at sea; improve crop planning and yields through better predictions of El Nino	Cancelled
Landsat Data Continuity	Land cover	Monitor deforestation; find mineral resources; track the conversion of agricultural land to other uses	Reformulated (instruments to be included on NPOESS)
Glory	Optical properties of aerosols; solar irradiance	Improve scientific understanding of factors that force climate change	Unclear
Wide Swath Ocean Altimeter (on the Ocean Surface Topography Mission)	Sea level in two dimensions	Monitor coastal currents, eddies, and tides, which affect fisheries, navigation, and ocean climate instrument	Overall mission on schedule. Altimeter instrument not included in mission

In addition to reducing funding for specific large missions, NASA has sharply reduced the Earth System Science Pathfinders (ESSP), a research program to launch small, experimental satellites that can test ideas for future larger missions. ESSP missions are not allowed to cost more than about $230 million over the life of the mission (as opposed to close to $1 billion for GPM). NASA now plans to delay for a year the ESSP proposal solicitation that was scheduled for this summer. The NAS Committee interim report calls for NASA to go forward with the solicitation this summer.

(ESSP launches approved from previous solicitations are on schedule. Two should launch this year.)

NASA has also substantially cut its Earth science research and analysis program, which focuses on developing the tools and techniques to interpret Earth science data. The program also helps scientists determine how to prioritize potential future research missions. These cuts particularly affect graduate student funding. According to the NAS Committee interim report, the research and analysis programs at NASA have suffered disproportionately large cuts.

The NAS Committee interim report also notes that the Earth science reductions could jeopardize NASA's ability to fulfill its obligations to interagency initiatives, such as the development of a Global Earth Observing System of Systems (GEOSS). This international effort will develop a comprehensive and coordinated Earth observing system. Earlier this year, Secretary of Commerce Carlos Gutierrez represented the United States at the meeting in Brussels where the GEOSS plan was adopted.

The NAS Committee interim report also calls into question NASA's ability to fulfill its commitments to the Climate Change Science Program (CCSP). NASA's Earth Science program represents the largest portion of the CCSP budget, (62 percent in the President's FY 2006 budget request).

Questions for the Witnesses

The witnesses were asked to address the following questions in their testimony:

Questions for Alphonso Diaz

Please briefly explain the President's FY06 budget request for NASA Earth sciences and answer the following questions:

- What missions that were in the planning process as of the FY 2004 budget submission have been delayed, canceled or reformulated? What criteria have NASA used in determining which missions to delay, cancel or reformulate? How do these criteria relate to NASA's larger vision for its Earth science programs?
- Given the FY06 budget run-out, to what extent will NASA have to limit its contributions to multiple agency programs such as the Climate Change Science Program (CCSP) and the Global Earth Observing System of Systems (GEOSS)?

Questions for Dr. Berrien Moore

Please summarize the NRC report, and answer the following questions:

- What are the Committee's greatest concerns for the funding outlook for NASA Earth sciences?
- How should NASA prioritize currently planned and future missions? What criteria should NASA use in doing so?
- What are the highest priority unaddressed or unanswered questions in Earth science observations from space?

Questions for Dr. Tim Killeen

- How should NASA prioritize currently planned and future missions? What criteria should NASA use in doing so?
- What are the highest priority unaddressed or unanswered questions in Earth science observations from space?
- What have been the most important contributions to society that have come from NASA Earth sciences over the last decade (or two)?
- What future benefits to the Nation (societal applications) are possible that NASA Earth sciences could provide? What gaps in our knowledge must we fill before those future benefits are possible?

Questions for Dr. Marcia McNutt

- How should NASA prioritize currently planned and future missions? What criteria should NASA use in doing so?
- What are the highest priority unaddressed or unanswered questions in Earth science observations from space?
- What have been the most important contributions to society that have come from NASA Earth sciences over the last decade (or two)?
- What future benefits to the Nation (societal applications) are possible that NASA Earth sciences could provide? What gaps in our knowledge must we fill before those future benefits are possible?

Questions for Dr. Sean Solomon

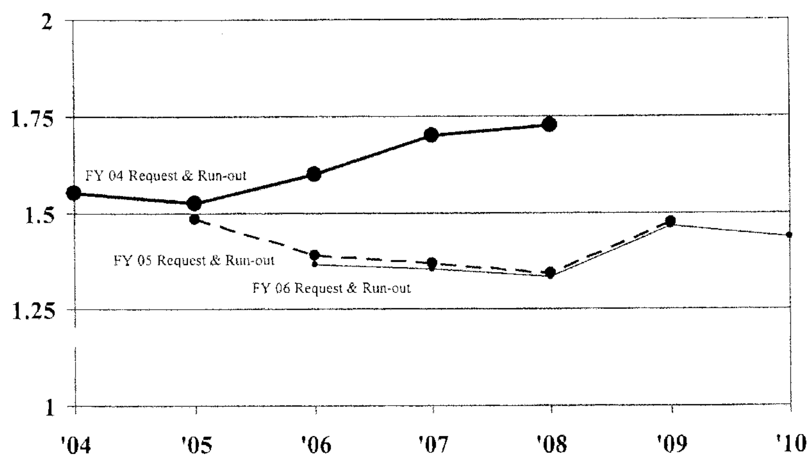
- How should NASA prioritize currently planned and future missions? What criteria should NASA use in doing so?
- What are the highest priority unaddressed or unanswered questions in Earth science observations from space?
- What have been the most important contributions to society that have come from NASA Earth sciences over the last decade (or two)?
- What future benefits to the Nation (societal applications) are possible that NASA Earth sciences could provide? What gaps in our knowledge must we fill before those future benefits are possible?

Questions for Dr. Ray Williamson

- How should NASA prioritize currently planned and future missions? What criteria should NASA use in doing so?
- What are the highest priority unaddressed or unanswered questions in Earth science observations from space?
- What have been the most important contributions to society that have come from NASA Earth sciences over the last decade (or two)?
- What future benefits to the Nation (societal applications) are possible that NASA Earth sciences could provide? What gaps in our knowledge must we fill before those future benefits are possible?

Appendix A

NASA Earth Science
Budget Request and 5-Year Run-outs
(In Billions of Dollars)



Thick solid line (top – beginning in '04): FY2004 request and 5-year run-out
Dashed line (middle – beginning in '05): FY2005 request and 5-year run-out
Thin solid line (bottom – beginning in '06): FY2006 request and 5-year run-out
(For FY2006, this is the Earth science portion of the "Earth-Sun System" theme – see below)

NASA Earth-Sun System Funding ($=millions)

	FY05	FY06	FY07	FY08
FY05 President's Budget	2231.3	2171.0	2155.2	2301.3
FY06 President's Budget	2155.8	2063.6	2081.2	2132.2
Change	-75.5	-107.4	-74.0	-169.1

THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

Space Studies Board

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April 25, 2005

Dear Colleague:

I am pleased to provide you with a prepublication copy of the report *Earth Science and Applications from Space. Urgent Needs and Opportunities to Serve the Nation.* This brief interim report of the NRC study titled "Earth Science and Applications from Space: A Community Assessment and Strategy for the Future" (the decadal survey) was prepared in response to discussions among agency sponsors, congressional staff and the committee. The report also responds, in part, to direction in the FY 2005 appropriations bill that calls for "the National Academy's Space Studies Board to conduct a thorough review of the science that NASA is proposing to undertake under the space exploration initiative and to develop a strategy by which all of NASA's science disciplines . . . can make adequate progress towards their established goals, as well as providing balanced scientific research in addition to support of the new initiative."

The purpose of the interim report is to identify urgent, near-term issues that require attention prior to completion of the full decadal survey, including the following:

- Consequences of the cancellation, delay, or descope of important NASA Earth science missions,
- Capability of NPOESS to fulfill the objectives of some of the above missions,
- State of the technological base for future missions,
- Impact of delays in the selection and launch of Earth System Science Pathfinders,
- Vitality of the NASA Research and Analysis program, and
- Need for a strategy to obtain baseline climate observations and to develop climate data records.

Space-based observations have a central role in advancing programs to understand the Earth system and how it supports life; they also are critical to a broad range of programs of enormous societal benefit. Therefore, an overriding concern of the committee is the absence of a robust mission queue for the future Earth science missions that will build logically on the highly successful EOS missions. Knowledge anticipated from analysis of EOS long-term data records rests now on a precarious plan to use instruments on the nation's next generation of weather satellites—NPOESS, scheduled for launch in 2009, and a new GOES series, scheduled for launch in 2012—foreign missions, and the occasional launch of small Explorer-class missions. In fact, aside from several delayed Explorer-class missions, the Ocean Surface Topography Mission (a follow-on to the current Jason-1 mission), and the Global Precipitation Measurement mission, the NASA program for the future has *no* explicit set of Earth observation mission plans. The enclosed report discusses these issues in more detail and recommends a course of action.

The committee is now turning its attention to the decadal survey, which is scheduled to be completed in late 2006. The committee's final report will include a consensus of the top-level scientific questions that should drive Earth and environmental observations in the period 2005-2015; it will also present a prioritized list of recommended space programs, missions, and supporting activities to address these questions.

We would be pleased to arrange for a briefing by the co-chairs or other committee members. Please do not hesitate to contact me if you have any questions. I can be reached by telephone at (202) 334-3477 or by e-mail at acharo@nas.edu. Thank you.

Sincerely,

Arthur Charo
Study Director

12 SPACE NEWS
April 4, 2005

REMOTE SENSING

Radar Imagery Aiding California Coastal Pollution Study

JASON BATES, WASHINGTON

NASA researchers recently completed a study using radar imagery collected by Canadian and European satellites to monitor pollution hazards off the coast of Southern California.

The effort is intended to demonstrate how the satellite imagery can help government officials make decisions in protecting coastal regions from pollution hazards, said Paul DiGiacomo, Earth missions concepts groups supervisor at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, Calif.

"Coastal regions are very popular places for people to live, work and play, and a significant fraction of the U.S. population lives at coastal regions," DiGiacomo said. About 20 million people live near the coast of Southern California, nearly 25 percent of the U.S. coastal population, he said.

The study focused on three major sources of pollution for the Southern California region:

- Storm water runoff created when pollutants collected on concrete surfaces are washed into the ocean by storms;
- Discharge from wastewater treatment plants; and
- Seepage from oil drilling operations such as those in the Santa Barbara Channel and in Santa Monica Bay.

JPL scientists, along with researchers from the University of California at Santa Barbara and the University of Southern California in Los Angeles, combined radar imagery collected by the European Space Agency's European Remote Sensing Satellites 1 and 2 and Canada's Radarsat spacecraft with ground-based measurements to study the impact of the pollutants.

"The notion of using satellites for these type of studies came up soon after satellites were launched," DiGiacomo said. "You can see a larger part of the ocean at one time, and you can revisit the area more quickly depending on the satellite and the sensor."

"We want to know where the potential hazards are going and where they will be tomorrow and where they will be in 48 hours and in 72 hours."

Paul DiGiacomo

The synthetic aperture radar, which can collect data regardless of weather conditions or time of day, offered advantages over sensors that operate in the visible spectrum, because storm water runoff data must often be collected in cloudy conditions, DiGiacomo said.

The satellite data was then combined with other ground-based measurements, including measurements of discharge from rivers in the region and ground-based radar data on surface ocean currents, DiGiacomo said.

The river flow data let researchers know how much water was being released into the ocean and when, and that information can be cross-referenced with the synthetic aperture radar data to detect changes in the amount of pollutants in the ocean, DiGiacomo said. The ocean current data provided information on which direction the currents would carry the pollutants and how quickly, he said.

"Every observational tool has strengths and weaknesses and where you get the most value is by putting them all together," DiGiacomo said. "We point out the information that satellite radar can provide and what it doesn't do, but when you put all of this together you have a robust system in place that can support our goal."

The Radarsat data was provided under the Radarsat-1 Application Development and Research Opportunity 2 program, a joint NASA and Canadian Space Agency effort designed to develop and demonstrate applications using Radarsat-1 data, DiGiacomo said. The European satellite data was provided by the European Space Agency under a separate JPL request, he said.

The current research effort was not intended to develop an operational system for monitoring pollutants but to demonstrate the utility of the data, which could lead to further research efforts, DiGiacomo said.

"What we wanted to do was better understand pollution hazards based on the information radar imagery gives us," DiGiacomo said. "We want to know where the potential hazards are going and where they will be tomorrow and where they will be in 48 hours and in 72 hours."

JPL already is participating in a regional Southern California marine water quality monitoring survey that involves more than 60 other organizations.

"There is ongoing work in this area, and our thinking was to further develop the use of radar imagery as a tool in the United States," DiGiacomo said. "We're trying to target this for U.S. coastal managers and get them to think of this as a tool to highlight now for urban coastal areas."

That project and future efforts will bring in other types of satellite data such as information from the Moderate Resolution Imaging Spectroradiometer (MODIS) instruments carried aboard several NASA spacecraft, he said. JPL also is looking at planned satellites, such as Canada's Radarsat 2, which is scheduled for launch in early 2006.

"One thing that is happening, and we would like to have happen, is to get a bigger groundswell of awareness of the capability of imaging radar for this application," DiGiacomo said. "Some people are aware, but there are many more that aren't. We're trying to publicize the capabilities and make sure this data is available in the future and use this and other data for future models."

Chairman BOEHLERT. Good morning. The Committee will come to order.

It is a pleasure to welcome everyone here this morning for our hearing on one of NASA's primary mission areas: the Earth sciences.

We are very pleased that NASA's new Administrator, Mike Griffin, has very clearly and unequivocally reinforced NASA's commitment to Earth science. For example, both Senator Allen, during the confirmation process, and this is a direct quote, "There are activities, including Earth sciences research, which have little in common with the needs of exploration and with which NASA has had a long-term involvement. Thus, NASA has certain responsibilities in these areas, which cannot and should not be set aside. And I am committed to continuing exploration of the Earth's environment at NASA." And that is the end of the quote from Administrator Griffin in the Senate confirmation hearing.

Unfortunately, NASA's prepared testimony for today's hearing is more problematic. The testimony describes Earth science research as being significant to the extent that it informs our knowledge of and our capability to explore other planets. This is precisely backwards. The planet that has to matter most to us is the one we live on. You would think that would go without saying. And we are woefully ignorant of the way this planet works, of the functioning of the land, the oceans, and the atmosphere and how they interact. It is great if Earth science can contribute to exploration and greater still if exploration of other planets could teach us more about the planet Earth.

But the Earth science program doesn't exist as some secondary adjunct of the exploration program. It exists to help us understand the planet we depend on, and there is no reason that NASA can't robustly carry out the President's Vision for Space Exploration while conducting vital Earth science research. In fact, that is what NASA has to do.

That is why the National Academy of Sciences' report that was released just yesterday is so alarming. The report indicates that NASA may be allowing its Earth Science Program to erode, perhaps irretrievably, just as we are beginning to understand more about the Earth's processes, just as our technology offers unprecedented opportunities, just as the Administration has announced new international commitments to Earth observation.

This report has to be a red flag for all of us. We need to stop, examine what is happening, and make sure that the fiscal year 2006 budget for NASA, whatever its top-level number, include adequate funding to keep Earth science moving forward for the foreseeable future. We need a vision for Earth science and priorities for Earth science just as we need to do more for exploration and aeronautics.

Yesterday, I heard, for the first time, a rationale from Dr. Diaz for the proposed cuts in Earth science, and I have to say, I found it a little bit troubling rather than convincing. He argued that some of NASA's projects could be launched on NOAA satellites and that some other aspects of Earth science could migrate to NOAA.

Now we all want NASA and NOAA to work together even better. In fact, we plan to hold a hearing in the next couple of months bringing the two agencies together to look in more detail at their relationship. But having NASA claim that NOAA will take over activities when there is no indication of that in NOAA's plan or budget strains. It is a sound of one hand clapping, and it won't get any applause from us.

NASA has long been the lead agency for space-based Earth science research. NOAA has operational responsibilities. The two agencies have complementary missions, and the more they can cooperate, the better. But one agency cannot substitute for the other, and no agency can build, launch, or use data from satellites without money.

Mr. Diaz told us yesterday he had no visibility into NOAA's budget. You would think a window into a partner agency's budget would be a prerequisite for transferring responsibilities. If NASA has plans to rely more on NOAA, those plans ought to be shared and reviewed with us and with the scientific community. Just setting the notion of relying on NOAA as an after-the-fact budget rationalization, I think, is playing with fire.

We have before us today the experts with whom we can begin a thoughtful, detailed, and realistic discussion about what NASA needs to do to ensure that we have a healthy national Earth science program. I can't think of anything more vital to our survival on the planet that is most important to us, the planet Earth.

Mr. Gordon.

[The prepared statement of Chairman Boehlert follows:]

PREPARED STATEMENT OF CHAIRMAN SHERWOOD L. BOEHLERT

It's a pleasure to welcome everyone here this morning for our hearing on one of NASA's primary mission areas—the Earth sciences. I'm very pleased that NASA's new Administrator, Mike Griffin, has very clearly and unequivocally reinforced NASA's commitment to Earth science.

For example, he told Senator Allen during the confirmation process, "[T]here are activities, including Earth Sciences. . .research, which have little in common with needs of Exploration, and with which NASA had had a long-term involvement. Thus, NASA has certain responsibilities in these areas which cannot and should not be set aside." And Dr. Griffin told Senator Dorgan, "Earth science continues to be vitally important and I am committed to continuing exploration of the Earth's environment at NASA."

Unfortunately, NASA's prepared testimony for today's hearing is more problematic. The testimony describes Earth science research as being significant to the extent that it informs our knowledge of, and our capability to explore other planets. This is precisely backwards. The planet that has to matter most to us is the one we live on. You'd think that would go without saying. And we are woefully ignorant of the way this planet works—of the functioning of the land, oceans and atmosphere and how they interact.

It's great if Earth science can contribute to exploration, and greater still if exploration of other planets could teach us more about the Earth.

But the Earth science program doesn't exist as some secondary adjunct of the exploration program. It exists to help us understand the planet we depend on. And there's no reason that NASA can't robustly carry out the President's Vision for Space Exploration while conducting vital Earth science research. In fact, that's what NASA has to do.

That's why the National Academy of Sciences report that was released yesterday is so alarming. The report indicates that NASA may be allowing its Earth science program to erode, perhaps irretrievably, just as we are beginning to understand more about the Earth's processes, just as our technology offers unprecedented opportunities, just as the Administration has announced new international commitments to Earth observation.

This report has to be a red flag for all of us. We need to stop, examine what's happening, and make sure that the fiscal 2006 budget for NASA—whatever its top-level number—include adequate funding to keep Earth science moving forward for the foreseeable future. We need a vision for Earth science, and priorities for Earth science, just as much as we do for exploration and aeronautics.

Yesterday, I heard for the first time a rationale from Mr. Diaz for the proposed cuts in Earth science. And I have to say I found it more troubling than convincing. He argued that some NASA projects could be launched on NOAA satellites and that some other aspects of Earth science could migrate to NOAA.

Now we all want NASA and NOAA to work together even better. In fact, we plan to hold a hearing in the next couple of months bringing the two agencies together to look in more detail at their relationship. But having NASA claim that NOAA will take over activities when there is no indication of that in NOAA's plans or budget strains credulity. It's the sound of one hand clapping, and it won't get any applause from us.

NASA has long been the lead agency for space-based Earth science research. NOAA has operational responsibilities. The two agencies have complementary missions, and the more they can cooperate the better. But one agency cannot substitute for the other, and no agency can build, launch or use data from satellites without money.

Mr. Diaz told us yesterday he had "no visibility" into NOAA's budget. You'd think a window into a partner agency's budget would be a prerequisite for transferring responsibilities. If NASA has plans to rely more on NOAA, those plans ought to be shared and reviewed with us and with the scientific community.

Just citing the notion of relying on NOAA as an after-the-fact budget rationalization is playing with fire.

We have before us today the experts with whom we can begin a thoughtful, detailed and realistic discussion about what NASA needs to do to ensure that we have a healthy, national Earth science program. I can't think of anything more vital to our survival.

Mr. Gordon.

Mr. GORDON. Thank you, Mr. Chairman, and good morning.

I would like to welcome the witnesses to today's hearing on NASA's Earth Science program. We have a distinguished panel of witnesses, and I look forward to their testimony.

Let me first say that you—that we all live now in a city with lots of conflicts and where Democrats and Republicans often times disagree frequently and legitimately on issues. But let there be no mistake, I want to concur with the Chairman's statement today. On this committee, I think we are in complete sync on his statement and on the direction that we need to move.

And so I say that so that folks don't think that there is a crack in the window that through stalemate more autocratic decisions can be made. So just for the record, I would like for you to know that.

NASA's Earth Science program has long been one of NASA's core missions, yet NASA's core missions are increasingly threatened by the new budgetary priorities contained in the President's exploration initiative. Just last month, the Space and Aeronautics Subcommittee heard about the precarious state of NASA's Aeronautics programs from a range of expert witnesses. One month before that, this committee heard from Acting Administrator Gregory that some 2,000 existing jobs at the NASA centers would be eliminated by the fall of next year, although we were unable to get any clear explanation of the rationale for the cuts or the process by which they would be made.

Today, we are going to hear more bad news from a panel of expert witnesses. The bottom line appears to be that NASA's Earth Science program faces the prospects of being marginalized in the coming years as the Agency puts its focus on the President's exploration initiative.

Let me quote some excerpts from the National Research Council's just-released interim report on Earth sciences. And I quote: "Today, this system of environmental satellites is at risk of collapse. . .NASA has no plan to replace its Earth Observing System platforms after their nominal six-year lifetimes end. . .and it has canceled, de-scoped, or delayed at least six planned missions—"

The NRC committee goes on to say, and I quote: "These decisions appear to be driven by a major shift in priorities at a time when NASA is moving to implement a new vision for space exploration. This change in priorities jeopardizes NASA's ability to fulfill its obligations in other important presidential initiatives, such as Climate Change Research Initiative and the subsequent Climate Change Science Program. It also calls into question future U.S. leadership in the Global Earth Observing System of Systems, an international effort initiated by the current Administration."

That is tough language, but it appears to be consistent with the facts.

I count myself among strong supporters of exploration, but as I said on previous occasions, we have to be willing to pay for it. We shouldn't try to implement it by cannibalizing NASA's other important programs.

Yet the fact is that when the President cut $2.5 billion from NASA's funding plan for fiscal year 2006 through 2009 relative to what he had promised just a year earlier, NASA imposed 75 percent of the cut on NASA's Science and Aeronautics program and only 10 percent on NASA's Exploration Systems program.

In reality, fiscal year 2006 funding requests for NASA's Earth Science Research program is $647 million lower than the funding plan for fiscal year 2006 contained in the fiscal year 2004 budget request. That is a reduction of 24 percent in just two years.

It is no wonder that the Earth science program is canceling and delaying missions. And the problem has been compounded by NASA's apparent unwillingness or inability to date to develop a long-term vision for Earth science and application programs.

So where does all of this leave us?

Let me quote the National Research Council once again: "Today the Nation's Earth Observatory program is at risk."

And let me remind you of a hearing just, I guess, a couple of years ago when Richard Blomberg of the National Shuttle Safety Panel had something similar to say, that that Shuttle was at risk. I don't think he meant that it was going to happen the next day, but he was correct.

And once again, let me quote this: "Today, the Nation's Earth observatory program is at risk." I think we need to take that seriously.

I want to hear our NASA witnesses respond to the National Research Council's findings. Does NASA dispute the facts presented by the NRC? And if not, why has NASA let its Earth science program reach this state of affairs? And most importantly, what is NASA's long-term commitment to Earth science and applications research, and what, if anything, is NASA prepared to do to reverse the current trend?

As our Chairman said earlier, I suspect part of the answer is these functions will be picked up by NOAA. Well, if that is the case, I would like to know what that amount of cost will be and what funding, additional funding, would be going to NOAA to pick that up.

In closing, I again want to thank the witnesses for participating in today's hearing. I look forward to your testimony.

[The prepared statement of Mr. Gordon follows:]

PREPARED STATEMENT OF REPRESENTATIVE BART GORDON

Good morning. I'd like to welcome the witnesses to today's hearing on NASA's Earth Science program. We have a distinguished panel of witnesses, and I look forward to their testimony.

NASA's Earth Science program has long been one of NASA's core missions. Yet NASA's core missions are increasingly threatened by the new budgetary priorities contained in the President's exploration initiative.

Just last month, the Space and Aeronautics Subcommittee heard about the precarious state of NASA's aeronautics programs from a range of expert witnesses.

One month before that, this committee heard from Acting Administrator Gregory that some 2,000 existing jobs at the NASA Centers would be eliminated by the fall of next year. Although we were unable to get any clear explanation of the rationale for the cuts or the process by which they would be made.

Today we are going to hear more bad news from a panel of expert witnesses.

The bottom line appears to be that NASA's Earth Science program faces the prospect of being marginalized in the coming years as the Agency puts its focus on the President's exploration initiative.

Let me quote some excerpts from the National Research Council's just-released interim report on the Earth Sciences:

> *"Today, this system of environmental satellites is at risk of collapse. . .NASA has no plan to replace its Earth Observing System platforms after their nominal six-year lifetimes end. . .and it has canceled, de-scoped, or delayed at least six planned missions. . .*

The NRC committee goes on to say:

> *"These decisions appear to be driven by a major shift in priorities at a time when NASA is moving to implement a new vision for space exploration. This change in priorities jeopardizes NASA's ability to fulfill its obligations in other important presidential initiatives, such as the Climate Change Research Initiative and the subsequent Climate Change Science Program. It also calls into question future U.S. leadership in the Global Earth Observing System of Systems, an international effort initiated by the current Administration."*

That is tough language, but it appears to be consistent with the facts.

I count myself among the strong supporters of exploration, but as I've said on previous occasions, we have to be willing to pay for it. We shouldn't try to implement it by cannibalizing NASA's other important programs.

Yet, the fact is that when the President cut $2.5 billion from NASA's funding plan for FY 2006 through 2009 relative to what he had promised just a year earlier, NASA imposed 75 percent of that cut on NASA's science and aeronautics programs and only 10 percent on NASA's Exploration Systems programs.

In reality, the FY 2006 funding request for NASA's Earth-Sun Science research program is $645 million lower than the funding plan for FY 2006 contained in the FY 2004 budget request. That's a reduction of 24 percent in just two years.

It's no wonder that the Earth Science program is canceling and delaying missions. And the problem has been compounded by NASA's apparent unwillingness or inability to date to develop a long-term vision for its Earth Science and Applications programs.

So where does all of this leave us?

Let me again quote the National Research Council's report:

> *"Today the Nation's Earth observation program is at risk."*

I want to hear our NASA witness respond to the National Research Council's findings. Does NASA dispute the facts presented by the NRC? And if not, why has NASA let its Earth Science program reach this state of affairs? And most importantly, what is NASA's long-term commitment to Earth Science and Applications research, and what—if anything—is NASA prepared to do to reverse the current trends?

In closing, I again want to thank the witnesses for participating in today's hearing, and I look forward to your testimony.

Chairman BOEHLERT. Thank you very much, Mr. Gordon.

And I think, for the audience, who are so familiar with atmosphere on Capitol Hill these days, how refreshing it is to see the same basic thrust of the remarks from both sides of the center aisle. This committee is noted for working cooperatively on important and sensitive subjects. We try to go forward together. That is not just a cliche; it is a *modus operandi.*

[The prepared statement of Mr. Costello follows:]

PREPARED STATEMENT OF REPRESENTATIVE JERRY F. COSTELLO

Good Morning. I want to thank the witnesses for appearing before the Committee to examine the state of the Earth science programs of the National Aeronautics and Space Administration (NASA).

The primary activities of NASA's Earth science programs are to develop and launch research satellites designed to improve our understanding of the land, oceans, and atmosphere. NASA missions have helped improve our knowledge and create new capabilities leading to advances in weather forecasting, storm warnings, and natural resource management.

I am aware that National Academy of Sciences (NAS) Committee on Earth Science Applications from Science is currently conducting a "Decadal Survey" for Earth science observations from space at NASA's request. This will be the first time a decadal survey has been conducted for Earth science and is expected to establish a prioritized list of research projects. I look forward to hearing from the NAS Committee Chair, Dr. Berrien Moore, to assess how the survey is progressing.

With regard to NASA's Earth Science budget for fiscal year 2006, I am aware that funding for the program has declined each year since FY 2004, and the President's FY 2006 budget submission continues this reduction. These budget reductions have led NASA to delay, cancel or scale back most Earth science missions. Furthermore, NASA has few if any additional Earth science missions in the planning pipeline beyond the missions that have been in the works for years. Also, NASA does not appear to have sufficient funds to launch some of the missions that it describes as being on schedule. If one of NASA's primary roles in the Earth sciences program is to build and launch research satellites to provide a deeper understanding of the basic processes governing the Earth's physical system, I am skeptical of NASA's ability to operate a successful Earth science program that lives up to its objectives.

Again, I thank the witnesses for appearing today and look forward to their testimony.

[The prepared statement of Ms. Johnson follows:]

PREPARED STATEMENT OF REPRESENTATIVE EDDIE BERNICE JOHNSON

Thank you, Mr. Chairman for calling this very important hearing today. I welcome our distinguished witnesses, and I would like to thank you for agreeing to testify here today on the importance of the NASA and their Earth Science programs.

The purpose of this hearing is to examine the state of Earth science programs of National Aeronautics and Space Administration (NASA).

The theme for Earth Science Week in 2004 was "Living on a Restless Earth." The global community is affected by the restless nature of our planet every day. Natural hazards such as earthquakes, storms, volcanoes, and landslides threaten our homes and businesses, but they also provide evidence of the incredible power and beauty of our planet. We were reminded of this incredible power this past December when South Eastern Asia was devastated by the horrific affects of a Tsunami.

As we discuss the enormous devastation caused by this natural disaster, the one question we must ask ourselves is could this have been avoided?

The space exploration research program has been one of the most successful research programs in the history of this country. Unfortunately, this year, NASA plans to cut $120 million or eight percent from last year's budget.

A newly released study by the National Academy of Sciences concluded that budget cuts threaten the vitality of NASA's Earth science programs.

Our challenge today is to achieve an increased public perception and awareness of the tremendous importance and value that the NASA's Earth Science programs for all people.

I agree with the assessment that Earth science is one of the most necessary and exciting fields of the science community today. I look forward to working with this committee on its advancement.

[The prepared statement of Mr. Udall follows:]

PREPARED STATEMENT OF REPRESENTATIVE MARK UDALL

Good morning. I'd like to join my colleagues in welcoming our witnesses to today's hearing. I am particularly eager to hear from Dr. Tim Killeen from the National Center for Atmospheric Research.

Dr. Killeen has been the Director of NCAR since 2000, and in that capacity he oversees the important research performed at NCAR. Of course, I have a particular interest in NCAR because it is located within my congressional district. But in addition, the Center's research has an impact nationwide since NCAR is operated by the University Corporation for Atmospheric Research—or UCAR—which includes 68 universities across the country.

With the collaboration of these universities, NCAR is able to perform research that is beyond the capabilities of any one university. So welcome, Dr. Killen—I look forward to your testimony.

Turning now to the topic of today's hearing, I will say up front that I am a strong believer in the importance of a strong national program in Earth science and applications. And I think that NASA, NOAA, and our universities have a critical role to play in increasing our understanding of the Earth and its environment through the collection and analysis of Earth observation data.

In addition to being of interest scientifically, commercial and governmental remote sensing data can and should be leveraged to meet a variety of important societal needs—including such things as land use planning, homeland security, and water resources management.

To that end, earlier this year I reintroduced H.R. 426, the *Remote Sensing Applications Act,* which is a bill that already passed the House in a previous Congress, and I look forward to working with Members on both sides of the aisle to advance its goals in this Session.

However, despite the importance of Earth science and applications research, all is not well with NASA's Earth Science program. Indeed, the just-released interim report of a Committee of the National Research Council makes it clear that NASA's Earth Science program is facing a serious threat to its future viability.

In that regard, the NRC report enumerates a whole series of planned missions and research activities that are being cut back or eliminated by NASA.

In addition, a number of currently operating missions that are still returning useful scientific data—such as Voyager—are threatened with premature termination.

While I certainly recognize that when ongoing missions lose their scientific productivity they need to be turned off to free up resources for newer missions, a number of the missions threatened with termination do not appear to fall into that category. I hope that NASA will take another look at those missions before doing something irrevocable.

Finally, I'm concerned by the push to eliminate or significantly delay planned NASA Earth Science missions such as the Landsat Follow-on mission and the Glory mission.

With respect to Landsat, there may well be good budgetary or operational reasons to consider moving a Landsat sensor onto NPOESS, the joint NOAA–DOD weather satellite currently under development. However, I am concerned that neither the technical impacts of such a move nor its likely cost impacts are well understood at this point.

I would hate for us to eliminate NASA's planned Landsat follow-on spacecraft now only to find out a few years down the road that trying to include a Landsat instrument on NPOESS is having unacceptable impacts on the NPOESS program. I fear that the ultimate outcome of such a situation could be a significant loss of Landsat data continuity.

I hope that the witnesses at today's hearing can help us better understand what the implications of putting NASA missions like Landsat onto the NPOESS spacecraft are, and what we will need to pay attention to if we agree to proceed down that path.

Well, Mr. Chairman, there are many other issues that I could mention, but at this point I would rather yield back my time so we can hear from our witnesses. Thank you.

[The prepared statement of Mr. Carnahan follows:]

PREPARED STATEMENT OF REPRESENTATIVE RUSS CARNAHAN

Mr. Chairman and Mr. Ranking Member, thank you for holding this important hearing today.

Over the past 30 years, NASA's Earth Science programs have resulted in important social and economic benefits, including improved weather forecasting and improved observation of sea surface winds and precipitation.

Better forecasts allow for more efficient evacuations and are crucial to for protecting populations in areas that are prone to natural disasters, including hurricanes, tornadoes, floods, earthquakes and tsunamis. Furthermore, businesses and infrastructure, including transportation and energy, are reliant on current forecasting and need improved weather information.

These improved Earth science findings are tremendously valuable—saving precious human lives and property. I would be surprised to find more than a handful of congressional districts in our nation that do not risk some form of natural disaster. These are crucial programs that all of as public servants have an obligation to make certain are maintained.

[The prepared statement of Ms. Jackson Lee follows:]

PREPARED STATEMENT OF REPRESENTATIVE SHEILA JACKSON LEE

Chairman Boehlert, Ranking Member Gordon,

I want to thank you for organizing this important hearing to discuss the status of NASA's Earth Science programs. While we often think of NASA's work to be solely in space, the truth is that NASA Earth Sciences have made many discoveries that impact our day to day lives right here on Earth. In fact the greatest knowledge we can learn is that of our own world because the discovery of this planet is far from complete.

There was a time in history when even scholars believed that Earth was flat. Obviously we have come a long way in terms of discovery since that time. We will always push the limits of innovation, but in order to do so we must invest the proper resources. Indeed, NASA's own mission statement begins with the goal, "To understand and protect our home planet." NASA research in Earth science has focused on understanding how the Earth's atmosphere, oceans, and land interact and operate as a whole. Unfortunately, NASA proposes to spend about $1.37 billion on Earth science research in Fiscal Year (FY) 2006, a cut of about $120 million, or eight percent, from FY 2005 (or about $180 million, or 12 percent, below the FY04 request). These cuts threaten many programs that would increase our knowledge of this Earth. In fact, the knowledge gained through Earth science could help avert many natural disasters. The tragic events following the earthquake and tsunami in South Asia highlight the global need for coordinated disaster preparedness and response. Seismometers detected the earthquake that triggered the tsunami and satellite altimeters detected the tsunami before it struck land. A tsunami warning system could potentially have saved tens of thousands of lives, but it did not exist in this region. In the aftermath of the disaster, a wide array of high-resolution satellite images and measurements are helping guide and monitor relief and recovery efforts and assisting in the deployment of resources (food, water, and medical supplies). As nations rebuild their devastated communities, Earth observations will provide critical inputs into decisions on the location, land use, and type of disaster-resistant construction practices that will improve human conditions in these disaster-prone regions.

I find it deeply unfortunate that these budget cuts will potentially end many successful programs that measure our environmental standard of life and could help us improve upon our condition. Many Earth observation missions have been canceled, delayed, or their scope has been severely limited. I have been a long time supporter of NASA in this committee and have supported the President's Vision for Space Exploration, but those endeavors should not cause us to limit our discovery right here on Earth. Again, the most important lessons we can learn are those about ourselves, because we as a human race must inhabit this Earth for many more generations to come and to limit our knowledge will only decrease our chances of doing so.

[The prepared statement of Mr. Green follows:]

PREPARED STATEMENT OF REPRESENTATIVE AL GREEN

I'd like to thank Chairman Boehlert and Ranking Member Gordon for the opportunity to discuss the state of Earth science programs at NASA. I had the opportunity to witness the devastation caused by the tsunami that occurred December 26, 2004. We have all seen the increasing devastation caused by the various hurricanes that hit Florida over the past year. We have all witnessed the variant climate changes from El Niño. Given the increasing vulnerability to extreme weather and climate variations, federal investments in these areas of research are more important than ever. I realize that we have a nation and a variety of good programs that will be affected by the tightening of our federal fiscal belt, so I relish the chance to speak to the experts on their views of the effects of such changes. To my knowledge, Earth science research is set to sustain about an eight percent cut from the last fiscal year, and I hope that any or all of you may be able to elaborate about what we will see as results.

Chairman BOEHLERT. Now with that, let me introduce our very distinguished panel, and I thank all of you for serving as resources for this committee.

First, we have Mr. Alphonso Diaz, the Associate Administrator at NASA for the Science Mission Directorate with whom I had a very constructive and productive meeting yesterday. Dr. Berrien Moore is the Co-Chair of the National Academy of Science's decadal survey, Earth Observations from Space, a Community Assessment and Strategy for the Future. Dr. Moore is also the Director for the Institute for the Study of Earth, Oceans, and Space at the University of New Hampshire. Dr. Moore, welcome. Dr. Tim Killeen is the Director of the National Center for Atmospheric Research in Boulder, Colorado. Doctor, welcome. Dr. Marcia McNutt is the President—oh, I have skipped Dr. Solomon. Excuse me. Well, I will get Dr. McNutt since I started. Dr. Marcia McNutt is the President and Chief Executive Officer of the Monterey Bay Aquarium Research Institute in Lost Landing, California. Doctor, welcome. Dr. Sean Solomon is the Director of the Department of Terrestrial Magnetism at the Carnegie Institution of Washington. Dr. Solomon, welcome. And finally, Dr. Ray Williamson is a Research Professor in the Space Policy Institute at the George Washington University. Doctor, welcome.

With that, you all are experienced in this process. You know, the drill. Essentially, we ask that you summarize in approximately five minutes. The Chair is never arbitrary when we have six distinguished witnesses before us, but if you can condense your opening remarks, that allows more opportunity for what is the most productive part of the hearing, and that is the dialogue between those of us who are privileged to be representatives and those of you in the wide world out there that we represent.

With that, Mr. Diaz, you are first up.

STATEMENT OF MR. ALPHONSO V. DIAZ, ASSOCIATE ADMINISTRATOR, SCIENCE DIRECTORATE, NASA

Mr. DIAZ. Thank you, Mr. Chairman, and thank you, Ranking Member Gordon, and Members of the Committee. I especially thank you Mr. Boehlert, Mr. Gordon, and Mr. Calvert, who I did meet with yesterday, and I think also we had a constructive discussion. So thank you very much for that.

As I have said yesterday and will say again, I think we have come a long way in my career at NASA over the past 30 to 40 years in our pursuit of understanding the Earth, the Solar System, and the Universe.

From our constellation of Earth Observation System Satellites helping to assess the emergence and spread of disease, the melting of glaciers, and the recovery efforts following the recent tsunami to our knowledge about life forms thriving in extreme environments helping us to understand and develop strategies to search for evidence of life beyond our home planet, NASA's accomplishments in Earth science are many and varied.

As one recent example, last week's edition of the *Journal of Science* published a new study showing that a decrease in snow cover in the Himalayas causes an increase in algal blooms thousands of miles away off the coasts of Somalia, Yemen, and Oman. This finding was based on data collected over the past two decades by instruments on four different satellites that reflect NASA's intergovernmental, interagency, and commercial partnerships; the Tropical Rainfall Measuring Mission, the Advanced Earth Observing System of Japan, the operational weather satellites that are operated by NOAA, and the instrument on Orbital Sciences Corporation Seastar.

We recognize that, as you indicated, Mr. Chairman, that by first understanding how to study the Earth as a planet, we can better prepare for sending humans to the Moon, Mars, and beyond. The Vision for Space Exploration and subsequent agency-wide transformation has presented NASA's science endeavors with an historic opportunity. By merging space science with its emphasis on discovery with Earth science's emphasis on capability for prediction, the Science Mission Directorate, I believe, is uniquely positioned to engage in comprehensive scientific investigations into the origin, evolution, and destiny of Earth, the Solar System, and the Universe.

We are in the midst of a transition in Earth science from a NASA-centric approach to a national strategy that maximizes all our national capabilities. These changes have created some anxiety, I recognized, and have caused some to question our commitment to Earth science. We have a responsibility to clarify the current strategy with all our stakeholders and to include them in the process as we go forward, and as I have said, we intend to do so.

There are several ways that I believe you can gauge our commitment to Earth science.

The actions in the 2005 budget, I believe, should be interpreted as a sign of the Administration's interest in accelerating the evolution of Earth science to a national program, not as a retreat from our NASA commitment to Earth science. The President's 2006 budget request will support a highly-effective program of research and development of Earth sciences that enables NASA to play a critical role in four major presidential directed programs: the Climate Change Science Program, the Global Earth Observing System of Systems, the Grand Challenges and Natural Disaster Reduction, and the Vision for Space Exploration.

As an example of our commitment to these initiatives, NASA's Earth science program contributes over 60 percent of the total funding to the Administration's Climate Change Science Program. The fiscal year 2006 budget request also supports several critical missions: 16 Earth science missions on orbit, eight missions scheduled to launch by 2010, and eight missions currently in formulation.

We have several exciting Earth science missions coming up with launches scheduled later this year, CloudSat and CALIPSO. In addition, we have several missions in development, such as the NPOESS Preparatory Project, NPP, that we are—that we and our partners believe are vital to evolving from research to operations.

Further, the Global Precipitation Mission is currently in formulation, along with several smaller missions in the Earth systems science pathfinder line.

While some Science Mission Directorate missions have been delayed one to two years to respond to other national priorities, this decision applies to all science missions that have not passed their confirmation review, not just those in Earth science.

To help chart our course ahead, we have established a two-pronged approach to obtaining community advice on the future of the Earth sciences at NASA. As part of the broader NASA planning effort to implement the Vision for Space Exploration, and other national objectives articulated in the New Age of Space Exploration, we have established 13 strategic road map committees, one specifically focused on the dynamic Earth system. We have recently received this committee's draft report and are pleased with the products and progress. We expect the final report within the next few weeks, and we will integrate them all into the Agency's next strategic plan.

NASA has also requested that the National Research Council generate a community-led decadal survey for Earth science. We are still digesting the recently received NRC Earth Science Decadal Survey Phase One Report, and we will carefully consider its recommendations together with our partners at NOAA.

While the decadal survey and the Dynamic Earth System Strategic Road map are still in development, some aspects of the direction we will take are already clear. We will continue working in partnerships with our international partners, as well as our interagency partners. We believe that that will provide us an implementation strategy that leverages our resources in a very effective way.

I would like to highlight the working relationship that NASA enjoys with NOAA, given the natural synergy and history of coordination and cooperation between Earth and space weather scientists and NASA and NOAA management. By partnering with NASA—excuse me, with NOAA, we are enabling improved weather prediction, severe storm forecasting, and climate prediction services. Further, we intend to increase our emphasis on having Earth science benefit our exploration program through the development of an operational capability to predict space weather.

Through our collaborative effort, not only can we answer questions of how and why the Sun varies, but also how the Earth responds to these changes and the implications of these changes to society. Understanding that is critical as we send humans to the Moon, Mars, and beyond.

We believe that we have effectively combined NASA's strengths in research and technology development with NOAA's capabilities to sustain a long-term operational system of satellites, creating the most effective system for American taxpayers.

I look forward to the upcoming launch of NOAA–N as some evidence of this and the launch of the NPOESS Preparatory Mission as further amplification.

Thank you, again, for the opportunity to appear, and I look forward to your questions.

[The prepared statement of Mr. Diaz follows:]

PREPARED STATEMENT OF ALPHONSO V. DIAZ

Mr. Chairman and Members of the Committee, thank you for this opportunity to appear today to discuss NASA's commitment to maintaining robust Earth and space science programs and their contributions to achieving the Nation's *Vision for Space Exploration.*

The Science Mission Directorate provides leadership to NASA at the agency level, delivering a unique scientific perspective. The Earth and space science activities of the Science Mission Directorate fully support NASA's mission to:

- Understand and Protect our Home Planet by using our view from space to study the Earth system and improve prediction of Earth system change
- Explore the Universe and Search for Life by continuing scientific investigations into the origin, evolution, and destiny of the universe and our solar system, and by applying our scientific understanding of the Earth system to the identification and study of Earth-like planets around other stars
- Inspire the Next Generation of Explorers by providing Earth and Space science content and training to educators, and by sponsoring the education and early careers of Earth scientists, astronomers, and physicists.

On January 14, 2004, President George W. Bush announced the *Vision for Space Exploration.* The President's directive gave NASA a new focus and clear objectives. The fundamental goal of this directive for the Nation's space exploration program is ". . .to advance U.S. scientific security, and economic interests through a robust space exploration program." In issuing this directive, the President committed the Nation to a journey of returning humans to the Moon, sending robots and ultimately humans to Mars, and exploring the solar system and beyond. He challenged us to establish new and innovative programs to enhance our understanding of the planets, to ask new questions and to answer questions as old as humankind. NASA enthusiastically embraced this directive and immediately began an agency-wide transformation to enable us to achieve the *Vision.*

NASA's recently published document, *The New Age of Exploration: NASA's Direction for 2005 and Beyond,* articulates NASA's commitment to implementing the *Vision for Space Exploration.* It identifies NASA's Guiding National Objectives to:

1. Implement a sustained and affordable human and robotic program to explore the solar system and beyond
2. Extend human presence across the solar system, starting with the Moon by the year 2020, in preparation for human exploration of Mars and other destinations
3. Develop innovative technologies, knowledge, and infrastructure both to explore and to support decisions about the destinations for human exploration
4. Promote international and commercial participation in exploration
5. Study the Earth System from space and develop new space-based and related capabilities for this purpose

NASA Earth science is critical for fulfilling NASA's mission because of NASA's unique capabilities of frequent global observations, modeling and data assimilation with the aim to improve prediction of both large-scale and small-scale processes. Human exploration of Mars and beyond requires prediction of the environment to be encountered by humans. The technological tools and scientific skills that NASA continues to develop through studying Earth, which has the most complex ecosystem with continuous interactions of biological, chemical and physical processes at all time and space scales, are critical in the exploration and search for life of other planets in our own solar system and beyond.

In June 2004, the President's Commission on the Implementation of the United States Space Exploration Policy, led by E.C. "Pete" Aldridge, Jr. (the Aldridge Commission), and reported their findings and recommendations to the President. The Aldridge Commission emphasized the crucial roles that technological innovation, national and international partnerships, and organizational transformation must play if we are to implement the President's *Vision* for an affordable and sustainable space exploration program. NASA is committed to making the necessary transformation to ensure our success in achieving the *Vision* for an affordable and sustainable space exploration program.

The Historic Opportunity to Implement the Vision

The transformation presents NASA's science endeavors with an historic opportunity to support and benefit from the *Vision for Space Exploration.* As the National Research Council stated in their report, *Science in NASA's Vision for Space Exploration* (2005), "the appropriate science in a vibrant space program is nothing less than that science that will transform our understanding of the universe around us, and will in time transform us into a space-faring civilization that extends human presence across the solar system."

In August 2004, NASA repositioned its science endeavors by merging two science Enterprises into one Science Mission Directorate with three themes: Earth-Sun System, Solar System Exploration, and Universe. The merger of Space Science, with its emphasis on "discovery," and Earth Science's capacity for "prediction" positions the Science Mission Directorate to support the *Vision* by engaging in comprehensive scientific investigations into the Origin, Evolution, and Destiny of the Earth, the Solar System, and the Universe. The synergies facilitated by this integration will benefit research, development, and improve science results in all NASA science disciplines, including Earth science. Furthermore, a unified Science Mission Directorate facilitates the opportunity for all of the discipline areas of science to learn from each other which, in turn, enhances NASA's exploration activities.

Planning for the Future

NASA has identified eighteen strategic objectives, from which thirteen strategic roadmaps will be derived. Six of these roadmaps directly apply to the activities and research objectives of the Science Mission Directorate. The current strategic planning process forms the basis for our future strategy for Earth and space science. Through our actions, we are clearly emphasizing a continuing commitment to Earth science and NASA's commitment to study the Earth system is clearly reflected in our national objectives. Not only will these studies better inform our work as we implement the *Vision,* but will strengthen our ability to continue to support Presidential initiatives involving climate change science and technology, the oceans, an integrated Earth observation system, and others.

Strategic Roadmapping

While the "Aldridge" Commission provided the blueprint for NASA's ongoing transformation in support of the *Vision,* NASA's strategic planning efforts are defining the specific details for *The New Age of Exploration.* New strategic roadmaps will provide a foundation for future investment decisions and priorities in 13 key areas. Each strategic roadmap is being developed by a team composed of nationally-recognized scientists, engineers, educators, visionaries, and managers, organized into dedicated teams co-chaired by senior NASA leaders and nationally recognized leaders from industry and academia. In some strategic roadmap areas, thematic roadmaps already exist or are in development. These "legacy" products and activities will be integrated into the new process.

The Dynamic Earth System roadmap committee submitted its interim status report to NASA for review on April 15. The work being done by this roadmapping committee has already identified a number of missions that NASA should consider in the future. For Earth science, the roadmap assumes the successful implementation of the currently planned mission set, such as the Orbiting Carbon Observatory, Aquarius, and the Global Precipitation Measurement missions. Likewise, for the Sun-Earth Connection, the roadmap assumes the successful implementation of STEREO, Solar-B, Magnetosphere Multi-Scale, Radiation Belt Storm Probes, and the Solar Dynamics Observatory missions.

In addition, the Dynamic Earth System and Sun-Solar System Connection roadmap committees are coordinating their activities and held a joint meeting on March 16, 2005. Interim reports from the two committees evidence interest in similar missions. Such missions have considerable importance for Earth science and the *Vision for Space Exploration* by enabling high-temporal resolution of atmospheric changes and solar influences on climate, and by providing a capability to monitor space weather and solar events that could be hazardous to spacecraft and astronauts.

Unlike the other roadmap committees, the Dynamic Earth System committee did not have the benefit of a National Research Council Decadal Survey as a starting input; such a survey was requested shortly before the roadmapping activity began and is currently in work. NASA expects to receive the final Phase II report by the end of calendar year 2006. However, the Dynamic Earth System committee will benefit from other detailed, strategic planning documents from NASA and national planning processes such as the U.S. Climate Change Science Plan, the Grand Challenges for Natural Disaster Reduction, and the U.S. Integrated Earth Observation System.

We have recently received the Dynamic Earth System committee's draft report and are pleased with the Committee's products and progress. We appreciate their hard work and support and value their contributions to this critical endeavor.

Decadal Study

At the request of NASA and NOAA, the National Research Council is carrying out a "decadal survey" entitled "Earth Science and Applications from Space: A Community Assessment and Strategy for the Future." The Space Studies Board, in consultation with other units of the NRC, will lead the study to generate consensus recommendations from the Earth and environmental science and applications communities regarding a systems approach to space-based and ancillary observations that encompasses the research programs of NASA and the related operational programs of NOAA.

The key goals of the study are:

- Articulate priorities for Earth system science and the space-based observational approaches to address those priorities.
- Establish individual plans and priorities within the sub-disciplines of the Earth sciences as well as an integrated vision and plan for the Earth sciences as a whole.

Providing Continued Leadership While Leveraging Partnerships in Earth Sciences

Presidential Initiatives

The FY06 budget supports critical national needs, including climate change by supporting investments in the U.S. Global Change Science and Technology Programs and next generation Earth observing satellites.

In addition to supporting the *Vision for Space Exploration,* NASA's Earth science program has a critical role in implementing important Administration initiatives:

- *Global Earth Observation System of Systems via the U.S. Group on Earth Observations*—The purpose of GEOSS is to achieve comprehensive, coordinated and sustained observations of the Earth system, in order to improve monitoring of the state of the Earth, increase understanding of Earth processes, and enhance prediction of the behavior of the Earth system. NASA's Earth Observing System supports this effort through a series of polar-orbiting and low inclination satellites, a science component, and a data system of long-term global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans.
- *Climate Change Science Program*—NASA's Earth science program is the largest contributor (over 60 percent of the total funding) to the Administration's Climate Change Science Program. NASA brings the global perspective from satellite and sub-orbital measurements to address climate and global change science questions. NASA has the end-to-end capability to develop technologies, models, deploy observing systems and utilize and provide products for decision support systems.
- *Grand Challenges in Natural Disaster Reduction*—NASA research and observations are essential to help the U.S. meet its disaster reduction goals for the next decade. Through its ability to view the Earth as a dynamic system, NASA makes key contributions to the science of hazard assessment and mitigation and provides essential support to the efforts of other federal agencies charged with these responsibilities.

International Partnerships

NASA has long-standing relationships with foreign countries in the conduct of Earth science. Historically, over 50 percent of NASA's Earth science programs have involved international participation. Such partnerships have allowed each country to leverage their Earth science resources to conduct outstanding science in the pursuit of understanding our Earth and the forces that influence its change. Cloudsat and CALIPSO, scheduled to launch this summer, exemplify how NASA is able to successfully collaborate with space agencies around the world. NASA and the Canadian Space Agency worked together to develop CloudSat's Cloud Profiling Radar. For CALIPSO, CNES, the French space agency, not only provided the spacecraft and the Imaging Infrared Radiometer (IIR), but is also performing payload-to-spacecraft integration and spacecraft mission operations.

In support of the *Vision for U.S. Space Exploration,* the Science Mission Directorate held a conference this past March that included participation from 26 international organizations. In some cases the participants were representatives from multilateral organizations such as the Central American Commission on Environment and Development (CCAD), the European Commission (EC), and the United Nations Educational, Scientific and Cultural Organization (UNESCO). The conference provided a forum for NASA and its international partners to exchange information on the *Vision* and to discuss opportunities for enhanced future cooperation. A recurring theme at the conference was the importance of international collaboration and information sharing in achieving common scientific priorities.

Interagency Partnerships

NASA works closely with our partner agencies on national programs including the Climate Change Science Program, the Grand Challenges in Disaster Reduction, and Integrated Earth Observation System. We value our long history of collaboration with research agencies, such as NSF and DOE, as well as operational agencies, such as EPA, USDA, DOI and NOAA. We are committed to continuing to work closely with our partner agencies to ensure the continuity of data sets crucial to our nation.

NASA and the U.S. Geological Survey (USGS) of the Department of Interior have cooperated to produce new global land cover data products for each of three different time periods: the 1970s, circa 1990, and circa 2000. The DOI (USGS) and NASA share responsibility for preserving and populating the National Satellite Land Remote Sensing Data Archive and ensuring the continued collection of Landsat data. The Landsat Program is the longest running enterprise for acquisition of imagery of the Earth from space. The first Landsat satellite was launched in 1972 and the most recent, Landsat 7, was launched in 1999. USGS's 33-year Landsat data archive provided most of the over 20,000 Landsat satellite images needed. In partnership with private industry (the Earth Satellite Corporation), the GeoCover product was created. Researchers, planners, and land managers are now using the GeoCover data to understand how the Earth's land cover and land use have changed over the past thirty years. Recent projects have documented urbanization in the U.S. and tracked land cover change on the biologically rich island of Madagascar. A new project is underway to map changes in North American forests since 1975 as part of the North American Carbon Program. GeoCover data also have been made available through two United Nations organizations, the UN Environment Programme (UNEP) and the Food and Agriculture Organization (FAO).

NOAA, NASA, U.S. Navy and U.S. Air Force jointly support the Joint Center for Satellite Data Assimilation (JCSDA) which seeks to accelerate and improve the quantitative use of research and operational satellite data in weather and climate prediction models. Recent successes have been based on data from a number of NASA satellites, including QuikSCAT, TRMM, Terra and Aqua. Through the JCSDA, inclusion of NASA data on sea winds, rainfall, high latitude winds and temperature and humidity vertical profiles in NOAA forecast models has led to improved NOAA weather forecast models, including short-term, hurricane and seasonal-to-inter-annual forecasts. The JCSDA helps to transform NASA's results into NOAA's operational systems and we are working together to ensure that each agency's models are sufficiently similar to allow for easy movement of progress from one to the other.

NASA and NOAA have also worked together to improve weather prediction on Earth Through a long-standing relationship where NASA acts as a program manager and purchasing agent on NOAA's behalf. This relationship in developing, launching, and operating the GOES and POES satellites has provided invaluable information used every day to forecast the weather, both in the U.S. and across the world. The launch of NASA-built NOAA N later this year will provide new short- and long-range forecasting capabilities.

In 1970, NASA's Nimbus–4 satellite led to the first measurements of global ozone content from space. Beginning with the Nimbus–7 in 1979, NASA and NOAA have harnessed this capability through the Total Ozone Mapping Spectrometers (TOMS) and the Solar Backscatter Ultraviolet (SBUV) instruments to produce a continuous 25-year data record of global ozone. The resulting long-term data set has been a central part of international assessments of the state of the ozone layer, showing both the global picture and trend of ozone loss and the progress of the Antarctic ozone hole. The continued data from this series of satellites will also play a key role in the observation of the recovery of the ozone layer. To interweave data from this series of satellite instruments into a homogeneous climate-quality data record requires the ongoing commitment of this interagency science team. This data record, and the blending of diverse strengths to analyze and verify data, continues today with the advanced ozone measurements being made by NASA's Aura mission. This capability will transition to NPOESS, with the first flight of the OMPS instrument suite aboard the NASA NPP mission.

More recently, NASA and NOAA have begun cooperating on missions related to space weather and its effects on Earth. Data from NASA spacecraft can be used to improve the NOAA capability to predict space weather. For example, NOAA uses data from NASA's solar wind monitoring ACE spacecraft to assist in predicting space weather. New NASA instruments will continue to inform the process needed to further develop a robust operational capability to predict space weather. By working together, NASA and NOAA are jointly able to answer questions of interest to both agencies: "How and why the Sun varies?"; "How does the Earth respond to solar variability?"; and "What are the implications of solar variability and the Earth's response?"

Based on this synergy of science objectives and history of coordination and cooperation, NASA has been working with NOAA to transition to a strategy that better leverages our respective strengths in science investigations and mission operations. NASA believes this is in line with the principles of good and efficient management of public funds to serve our nation and the world. It is our intent to continue to work with NOAA to look for new ways to improve the efficiency of these transfers. For example, both agencies have jointly funded a study by the National Academy of Sciences/National Research Council Committee on NASA–NOAA Transition from Research to Operations (CONNTRO). The May 2003 final report was called *Satellite Observations of the Earth's Environment, Accelerating the Transition from Research to Operations.* In addition, NASA and NOAA have established a Joint Research to Operations (R2O) Working Group as a mechanism for joint and coordinated planning on transition matters pertaining to research results, ground systems, and current and future spacecraft missions in preparation for discussions within the National Science and Technology Council.

FY 2006 Budget

The former Earth Science Enterprise and the Sun-Earth Connection theme from the former Space Science Enterprise have been combined to form the new Earth-Sun System theme. In this new theme, the following programs can be traced from Earth Science: Earth Systematic Missions, Applications and Earth System Pathfinders.

The FY 2006 budget supports a vibrant and effective science program that is responsive to national priorities. The overall NASA science programs budget run-out shows a 24 percent increase from FY 2006 through FY 2010, at which time science will grow from 33 percent to approximately 38 percent of the NASA budget. NASA's Science Mission Directorate continues to support 55 operational missions, 26 missions in development and 34 in formulation. There are 16 Earth Science missions presently on orbit and plans to launch eight more Earth Science missions between 2005 and 2010. Earth science missions in development include Cloudsat; the Cloud-Aerosol Lidar and Infrared Pathfinder (CALIPSO); the NPOESS Preparatory Project (NPP); the Orbiting Carbon Observatory (OCO); and the Landsat Data Continuity Mission (LDMC). In addition, the following Earth science missions are currently in formulation: the Ocean Surface Topography Mission (OSTM); the Global Precipitation Mission (GPM); Glory; Aquarius; and Hydros. Additionally, the NOAA reimbursable missions GOES–N, –O, and –P and POES–N and –N' are in development and GOES–R is in formulation.

One of NASA's Strategic Objectives for 2005 and beyond is to advance scientific knowledge of the Earth system through space-based observation, assimilation of new observations, and development and deployment of enabling technologies, systems, and capabilities including those with the potential to improve future operational systems. The FY 2006 budget for NASA supports a highly effective program of research and development of Earth Sciences, and plans are now being formulated to continue this significant effort into the future.

Conclusion

The integrated view of Sun and Earth as a system is reflected in our strategic roadmapping approach and long-term planning. NASA's goal is to continue using our unique view from space to study the Earth system and improve our prediction of the Earth system change. Through new space-based technology designed to monitor the Earth system, NASA will provide timely, on-demand data and analyses to users for scientific research, national policy-making, economic growth, natural hazard mitigation, and the exploration of other planets in this solar system and beyond. NASA's FY 2006 budget request supports a robust science and mission set to ensure a wealth of scientific research and discovery will continue well into the future. Through this approach we also recognize the emerging importance of understanding the Earth-Sun system in enabling the achievement of the *Vision* and NASA's exploration mandate.

BIOGRAPHY FOR ALPHONSO V. DIAZ

Mr. Alphonso V. Diaz was named Associate Administrator for NASA's Science Mission Directorate on August 8, 2004. In this position, he is responsible for the management, direction, and oversight of NASA's science flight programs, mission studies, and technology development. In addition, in this capacity, he is the designated Program Executive Officer for the Goddard Space Flight Center (GSFC), the Ames Research Center, and contract management of the Jet Propulsion Laboratory.

From 1996 to 2004, Mr. Diaz was at Goddard Space Flight Center where he served as Center Director from 1998 to 2004 and as Deputy Director from 1996 to 1998. While at GSFC he was responsible for planning, organizing, and directing NASA's Earth science, space science, and technology programs assigned to the Center. GSFC is engaged in developing and operating scientific spacecraft including the Hubble Space Telescope and the Earth Observing System. The Center continues to seek excellence in science and technology as demonstrated by many discoveries and advances in its history, from the first mapping of the Antarctic ozone hole to determining the very early structure of the universe.

From 1989 to March 1996, Mr. Diaz served as Deputy Associate Administrator and Chief Engineer of the Office of Space Science (Code S) at NASA Headquarters. In that capacity, he was responsible for management direction and oversight of space science flight program policy, launch vehicle requirements, technology infusion requirements, and mission study reviews and assessments. Mr. Diaz led the Agency committee charted by the Administrator to study proposals related to science institutes and to provide recommendations for implementation. Prior key positions with NASA include Deputy Associate Administrator for the former Office of Space Science and Applications (OSSA), Assistant Associate Administrator for Programs within OSSA, and Director for Strategic Plans and Programs for Space Station.

Mr. Diaz began his career at NASA's Langley Research Center as a NASA Coop Student in 1964. At Langley, he worked in a variety of technical management positions, including on the Viking Project, Gas Chromatograph Mass Spectrometer (GCMS). This scientific instrument was the first to analyze the surface material of Mars in 1976. In 1979, Mr. Diaz began his work at NASA Headquarters, where he served in a variety of positions. Aside from the positions mentioned above, Mr. Diaz also has served as the International Solar-Polar Mission (now Ulysses Mission) Program Manager, the Galileo Program Manager, Manager of Planetary Advanced Programs, and as Deputy Director of the Solar System Exploration Division. He later served as Assistant Associate Administrator for Space Station within OSSA, managing all activities on the use of the planned Space Station for scientific research, and providing strategic planning guidance for OSSA's overall program of scientific exploration. Mr. Diaz received three Presidential Rank Awards; two as Meritorious Executive in 1990 and in 1995, and one Distinguished Award in 1996. He also has received five NASA Medals, including a NASA Outstanding Leadership Medal in 1994 for his work on the Hubble Space Telescope First Servicing Mission, and an Exceptional Scientific Achievement Medal for his work on the Viking Project in 1976.

Mr. Diaz received a Bachelor of Science degree in Physics from St. Joseph's University in Philadelphia, Pennsylvania and a Master of Science degree in Physics from Old Dominion University in Norfolk, Virginia. In addition, he received a Master of Science in management from the Massachusetts Institute of Technology (MIT) Sloan School of Management in 1986 where he attended as a NASA Sloan Fellow. He has received an Honorary Doctorate in Science from Capital College and is scheduled to receive an Honorary Doctorate from the University of Rome (Italy) on May 30, 2005. He is a Fellow and Trustee of the International Academy of Astronautics and an Associate Fellow of the American Institute of Aeronautics and Astronautics. He is married to Angela Phillips Diaz. They reside in Takoma Park, MD.

Chairman BOEHLERT. Thank you very much, Mr. Diaz.

Dr. Moore.

STATEMENT OF DR. BERRIEN MOORE III, DIRECTOR, INSTITUTE FOR THE STUDY OF EARTH, OCEANS, AND SPACE, UNIVERSITY OF NEW HAMPSHIRE

Dr. MOORE. Thank you. Thank you Committee, Minority Member Congressman Gordon, and Members of the Committee. Thank you for inviting me here to testify today.

My name is Berrien Moore, and I am a professor of systems research at the University of New Hampshire. I appear today in my capacity as Co-Chair of the National Research Council's Committee on Earth Science and Applications from Space: A Community Assessment and a Strategy for the Future.

This committee came into being in response to requests from NASA, NOAA, and the USGS to begin a decadal survey of Earth sciences and applications from space. That committee's report, the final report, is due to be completed in late 2006.

The key tasks of the committee are to develop a consensus of the top-level scientific questions that should provide the focus for Earth and environmental observations for the period 2005 to 2020 and to develop a prioritized list of recommended space programs, missions, and supporting activities to address these questions.

I would like now to just simply summarize my comments more informally.

What we have submitted today, or actually released yesterday, is the interim report of the committee. Unfortunately, I don't think that is the best title. It is the report that the committee was asked to do, funded by the government and partnered by the community, to look at the status of affairs today, because if we are to try to set a decadal survey into motion to talk about a vision for 2005, but really in reality 2010 to 2020, we need to see where we are today.

And so the interim report is essentially a status of the bridge. Al Diaz mentioned quite properly that NASA's history in Earth science over the last 15 to 20 years is truly remarkable. So our past up to the present is of enormous strength. And I concur, having had this morning the opportunity to look at the road maps and to know what the decadal survey is doing, as we think about the period 2010 to 2020, that there is a glorious opportunity that we have to better understand this planet and to better serve the Nation and the world.

However, we are now on a bridge between that extraordinary past and the future. And there is concern about the status of that bridge. And that is the content of the interim report.

The concerns are in five areas.

For a variety of reasons, there have been a significant number of Earth science missions that have been delayed or descoped or canceled or terminated, and I can easily understand some debate about which of those verbs is most appropriate. But there has been a significant impact upon a set of Earth science missions that the community had expected to come into existence.

Secondly, part of the strategy of dealing with this challenge has been to move some of that capability from NASA to NOAA and put it onto the NPOESS platform. There are concerns about that transition. We do not understand fully the technological issues as well as the scientific.

I will return to that point in a moment.

Thirdly, that there are—that after the Global Precipitation Mission, there is no major facility-class mission at NASA in the planning queue. This is the first time that I can remember, in the long history I have had with NASA, to see that there is essentially an end. And when that occurs, it has an impact upon the technology investments. If you do not have a robust mission queue leading out into the future, then you do not have a robust technology cue to support that.

The Earth System Science Pathfinders are an extraordinary opportunity to have rapid access to space through principal investigator-led missions. I find this one of the most exciting aspects to see the Earth sciences adopt the Explorer mission concept from the space sciences and to have incorporated these in the so-called ESSP, the Earth System Science Pathfinders.

However, because of budget constraints again, these missions have been stretched out longer and longer. I think the theme is going to be "fly before I die" if we don't bring these in. We are looking at outwards of eight and 10 years to fly off some of these PI-led missions.

Two final areas.

In this transfer of capability from NASA to NOAA, there are extraordinary opportunities there. But there are some very real concerns. Take, for instance, we have had this wonderful success with the EOS missions. And those now are to be replaced, in part, by the operational NPOESS missions.

But let us look at what happens to the information that comes from NPOESS. It flows to four weather centrals, operational weather centrals. There is no science central. There is no climate central. There is no central where the data can be analyzed carefully and repeatedly. It goes to four operational centers that have enormously important but very significant time constraints for getting the information out.

And so we think that, in one of our recommendations, we need to look at this and ask: Is NPOESS really serving the scientific community, and in particular, the climate part of that mission?

Finally, when you have a constrained budget, or a budget that is falling, one of the hardest things in the world to do is to preserve the research and analysis. This is particularly true when many times you have built the research and analysis part of the budget through a coupling with the major missions. The EOS is a good example. Research and analysis in the Earth sciences was enhanced tremendously because of the close coupling with the Earth Observing System. That coupling is beginning to deteriorate as the Earth Observing System begins to age.

I would like to compliment, though, Ghassem Asrar, who has done everything he could—who is in the audience, who has done everything he could to preserve that research and analysis line. But in a declining budget, this becomes the first of many difficulties.

Let me conclude, and I would go back to my formal testimony.

Taken together, these developments jeopardize U.S. leadership in both Earth science and Earth observations, and they undermine the vitality of the government-university-private sector partnership that has made so many contributions to society.

Thank you for the opportunity to appear before you today, and I am prepared to answer any questions that you have.

[The prepared statement of Dr. Moore follows:]

PREPARED STATEMENT OF BERRIEN MOORE III

Mr. Chairman, Ranking Minority Member, and Members of the Committee: thank you for inviting me here to testify today. My name is Berrien Moore, and I am a Professor of Systems Research at the University of New Hampshire. I appear today in my capacity as Co-Chair of the National Research Council (NRC)'s Committee on Earth Science and Applications from Space: A Community Assessment and Strategy for the Future.

As you know the National Research Council is the unit of the National Academies that is responsible for organizing independent advisory studies for the Federal Government on science and technology. In response to requests from NASA, NOAA, and the USGS, the NRC has begun a "decadal survey" of Earth science and applications from space which is due to be completed in 2006. The guiding principle for the study, which was developed in consultation with members of the Earth science community, is to set an agenda for Earth science and applications from space, including everything from short-term needs for information, such as weather warnings for protection of life and property, to longer-term scientific understanding that is essential for understanding our planet, how it supports and sustains life, and that underpins future societal applications.

The NRC has been conducting decadal strategy surveys in astronomy for four decades. But it has only started to do them in other areas fairly recently. This is the first decadal survey in Earth science and applications from space.

Among the key tasks in the charge to the decadal survey committee is the request to:

- Develop a consensus of the top-level scientific questions that should provide the focus for Earth and environmental observations in the period 2005–2020; and
- Develop a prioritized list of recommended space programs, missions, and supporting activities to address these questions.

The NRC survey committee has prepared a brief interim report, which I am pleased to be able to summarize today. This report provides an early examination of urgent issues that require attention prior to publication of the committee's final report in the second half of 2006. A copy of the full report has also been provided for your use.

The report was requested by the sponsors of the study and by staff members of the Science Committee. The report also responds, in part, to direction in the FY 2005 appropriations bill that calls for "the National Academy's Space Studies Board to conduct a thorough review of the science that NASA is proposing to undertake under the space exploration initiative and to develop a strategy by which all of NASA's science disciplines. . .can make adequate progress towards their established goals, as well as providing balanced scientific research in addition to support of the new initiative."

The current U.S. civilian Earth observing system centers on the environmental satellites operated by NOAA; the atmosphere-, ocean-, ice-, and land-observation satellites of NASA's Earth Observing System (EOS); and the Landsat satellites, which are operated through a cooperative arrangement between NASA, NOAA, and the USGS. Over the past 30 years, NASA and NOAA have contributed to fundamental advances in understanding the Earth system and in providing a variety of societal benefits through their international leadership in Earth observing systems from space. *Today, this process of building understanding through increasingly powerful observations and thereby expanding the basis for needed applications is at risk of collapse.* Although NOAA has plans to modernize and refresh its weather satellites, NASA has no plan to replace its EOS platforms after their nominal six-year lifetimes end (beginning with the end of the Terra satellite mission in 2005), and it has canceled, scaled back, or delayed at least six planned missions, including a Landsat continuity mission.

These decisions at NASA appear to be driven by a major shift in priorities as the Agency moves to implement a new vision for space exploration. We believe this change in priorities jeopardizes NASA's ability to fulfill its obligations in other important presidential initiatives, such as the Climate Change Research Initiative and the subsequent Climate Change Science Program. It also calls into question future U.S. leadership in the Global Earth Observing System of Systems, an international effort initiated by this administration. Indeed, the Nation's ability to pursue a visionary space exploration agenda depends critically on our success in applying knowledge of the Earth to maintain economic growth and security on our home planet.

Moreover, a substantial reduction in NASA's Earth observation programs today will result in a loss of U.S. scientific and technical capacity, which will decrease the competitiveness of the United States internationally for years to come. U.S. leadership in science, technology development, and societal applications depends on sustaining competence across a broad range of scientific and engineering disciplines that include the Earth sciences.

The NRC's interim report identifies a number of issues for NASA and NOAA that require immediate attention in the FY 2006 and FY 2007 programs. They include the following:

- The impact of canceling or delaying NASA missions,
- The need to evaluate plans for transferring capabilities from some canceled or scaled-back NASA missions to the NOAA–DOD NPOESS satellites,
- The adequacy of the technological base for future missions,
- The state of NASA Research and Analysis programs, which are necessary to maximize scientific return on NASA investments in Earth science and to retain the intellectual base for future missions,
- The need to reinvigorate the Explorer missions program, and
- Near-term steps that are required to develop a sustained and robust observing system from space that provides essential baseline climate observations and create a climate data and information system to meet the challenge of production, distribution and stewardship of climate records from NPOESS and other relevant observational platforms.

With regard to these issues, the committee recommends the following actions:

1. The NASA Global Precipitation Measurement mission should be launched without further delays. This mission is an international effort to improve climate, weather, and hydrological predictions through more accurate and frequent precipitation measurements.
2. NASA and NOAA should complete the fabrication, testing, and space qualification of the GIFTS (Geosynchronous Imaging Fourier Transform Spectrometer) instrument and should support the international effort to launch this instrument by 2008. GIFTS will make highly detailed measurements from geostationary orbit of temperature and water vapor and will improve the prediction of severe weather conditions as well as the range of global weather forecasts.
3. NASA and NOAA should commission three independent reviews, to be completed by October 2005, regarding three missions or instruments: (a) the Landsat Data Continuity Mission, which has been endorsed by the White House Office of Science and Technology Policy and was planned by NASA to continue the vital record of Earth land imaging after Landsat–7, which is currently failing, (b) the Glory mission to measure and characterize atmospheric aerosols and solar irradiance, which is now canceled, but which NASA had previously proposed to accelerate in response to the President's Climate Change Science Program, and (c) the suitability of the instrumentation planned for NPOESS to measure ocean winds and direction.

   The guidelines for these reviews are set forth in the Interim report.

4. Mr. Chairman, we also recommend that NASA significantly expand existing technology development programs to ensure that new enabling technologies for critical observational capabilities are available to support mission starts over the coming decade. One of the problems of having nothing in the mission queue after the Global Precipitation Mission, other than smaller, principal investigator led explorer-class missions, is that focused technology development is no longer supported. Amongst the areas requiring increased technology investments are:
   - Space-based interferometric synthetic aperture radar, whose numerous applications include monitoring of Earth's crustal movements caused by volcanic or seismic activity;

- Wide swath ocean altimetry, which will provide the first synoptic observations of global ocean eddies, coastal currents and tides, and internal tides; and
- Wind lidar, which will facilitate long sought measurements of global wind profiles, particularly over the oceans where three dimensional measurements are sparse and where most weather phenomena originate.

5. We also recommend that NASA:

   - Increase the frequency of Earth Explorer selection opportunities and accelerate the frequency of launch opportunities by providing sufficient funding for at least one launch per year (that is, a return to the schedule the program originally envisioned and followed prior to recent delays), and
   - Release the next announcement of opportunity for this program in FY 2005.

   NASA developed its Earth System Science Pathfinder (ESSP) program as "an innovative approach for addressing Global Change Research by providing periodic 'Windows of Opportunity' to accommodate new scientific priorities and infuse new scientific participation into the Earth Science Enterprise. . .[using]. . .relatively low to moderate cost, small to medium sized missions that are capable of being built, tested and launched in a short time interval." But some of the missions now being planned may not be launched until nearly 10 years after they were selected.

6. Last, we recommend that NOAA, working with the Climate Change Science Program and the international Group on Earth Observations create a robust and sustained observing system from space that includes at a minimum a set of essential baseline climate observations. In addition NOAA should create a climate data and information system to meet the challenge of the production, distribution, and stewardship of high-accuracy climate records from NPOESS and other relevant observational platforms. These functions are within NOAA's mandate to understand climate variability and change, but cannot be accomplished through the current NPOESS program or its data system architecture.

Finally, Mr. Chairman, our committee is also concerned about diminished resources for the research and analysis (R&A) programs that sustain the interpretation of Earth science data. Because the R&A programs are carried out largely through the Nation's research universities, there will be an immediate and deleterious impact on graduate student, postdoctoral, and faculty research support. The long-term consequence will be a diminished ability to attract and retain students interested in using and developing Earth observations. Taken together, these developments jeopardize U.S. leadership in both Earth science and Earth observations, and they undermine the vitality of the government-university-private sector partnership that has made so many contributions to society.

Thank you for the opportunity to appear before you today. I am prepared to answer any questions that you may have.

Chairman BOEHLERT. Thank you, Dr. Moore.

Dr. Killeen.

STATEMENT OF DR. TIMOTHY L. KILLEEN, DIRECTOR, NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

Dr. KILLEEN. Good morning.

I thank Chairman Boehlert, Ranking Member Gordon, and the other Members of the Committee for the opportunity to speak with you today about NASA's role in the Earth sciences.

My name is Tim Killeen. I am the Director of the National Center for Atmospheric Research, or NCAR, which is sponsored by the National Science Foundation, and the President-Elect of the American Geophysical Union.

I am a space scientist who has built hardware for NASA in the past and a former professor at the University of Michigan where I taught Earth system sciences for many years.

I would like to make three simple points today.

First, NASA plays a crucial role in the country's vibrant Earth sciences program. Decisions about NASA priorities and funding on Earth science can accelerate or impede progress in this vitally important field.

Second, rapid advances in NASA Earth observing capabilities, when coupled with the acceleration of modeling and information technologies, have positioned us on the brink of an extraordinary new era in Earth science research, one in which we can quantitatively understand and predict the Earth as a system with tremendous societal and economic benefits.

Third, the importance of Earth science and the central role of NASA argue for careful, thorough, and deliberative assessment to inform program planning, especially when major changes are being considered. In my opinion, the current pace of budgetary and program change at NASA is inconsistent with such an approach and could result in irrevocable damage to programs and scientific teams that have taken decades and billions of tax dollars to build.

If I could have the first slide, please.

It is clear after many years of pioneering satellite observations that Earth is a system of tightly coupled parts that interact in complex ways to produce the whole. For me personally, this "blue marble" photograph taken over 30 years ago by Apollo 17 astronauts on the way to the Moon symbolizes this complex system. It has become a societal icon.

The study of such interactions has, in fact, become known as Earth system science and has led to numerous insights about how the Earth functions and how it is evolving and changing over time.

To understand, for example, how the atmosphere supports and protects life, one must appreciate the complex and tightly-coupled circulation dynamics, chemistry, interactions with the oceans, with ice, with biosphere and land surface, all driven by solar radiation. And the natural system that we live on—live in is susceptible to changes due to human activity, creating still more complexity and variability. We must strive to understand and predict such variability in order to safeguard and manage human societies.

Earth system science, informed by comprehensive and accurate ground- and space-based observations, is the tool kit for this.

Let me provide you with a single example of what I am talking about.

Just last week, President Bush mentioned proposed rules to limit air pollution from power plants.

The next slide, please.

These animations were the first NASA-produced global observations of air pollution moving around the globe. Sources of carbon monoxide seen here include industrial processes. See, for example, the source regions in the Pacific Rim, and fires, look at Amazonia. This global-scale data from space, thanks to NASA's commitment to research and innovation, has helped transform our understanding of the relationship of pollution and air quality. We now know that pollution is not solely, or even primarily, a local or regional problem. California's air quality, for example, is clearly influenced by industrial activity in Asia.

NASA Earth observation capabilities, such as these, thank you, coupled with the Agency's strong support for modeling and scientific research and analysis, have been essential to the advancement of Earth system science. It is very important to maintain this balance within the NASA program both because research and analysis is the process by which useful information is derived from remote sensing systems and because university-based research activities produce and nurture the human capital that provides a foundation for the entire space program.

In this slide, the effect of funding reaches far beyond the year in which they occur.

Advanced Earth observations and modeling, I assert, will lead directly to major societal benefits to the country, including improved national security, weather forecasts and warnings, climate outlooks, management of natural resources, including water, agriculture, and energy, and mitigation of natural disasters, such as droughts, floods, landslides, and volcanic eruptions.

I fully understand that NASA faces many difficult choices arising from pursuit of ambitious goals in a period of national budget constraints. However, I believe it is important to proceed carefully when making decisions regarding key national assets and programs such as these. Understanding the complex, changing planet upon which we live, how it supports life, and how human activities will affect its ability to support life into the future is one of the greatest intellectual and practical challenges facing humanity.

I urge the Members of the Committee to do all that is possible to protect and help to manage, in a thoughtful and strategic manner, the critically valuable scientific infrastructure and human capital that are unique to the NASA Earth Science program.

And I thank the Chairman and the Ranking Member, in particular, for the opening comments.

[The prepared statement of Dr. Killeen follows:]

PREPARED STATEMENT OF TIMOTHY L. KILLEEN

I thank Chairman Boehlert, Ranking Member Gordon, and the other Members of the Committee for the opportunity to speak with you today on NASA's role in the Earth Sciences. My name is Tim Killeen, and I am the Director of the National Center for Atmospheric Research (NCAR), which is sponsored by the National Science Foundation. I am also the President-Elect of the American Geophysical Union (AGU). My academic background is as an experimental space scientist who has participated in several NASA space science programs and a former professor at the University of Michigan, where I taught atmospheric, space, and Earth system sciences for many years.

The topic of this hearing is of tremendous importance to our understanding of the planet on which we live. I would like to make three fundamental points today, using examples of past and future contributions by NASA to the study of Earth:

- First, NASA plays a crucial role in this country's vibrant Earth sciences program. NASA is the dominant federal funding agency for U.S. scientists and engineers who address fundamental questions about our planet, provide practical knowledge about the way the Earth functions, and reveal how human activities affect the environment upon which all life depends. NASA funding for Earth science provides the intellectual capital and scientific infrastructure to produce work that is not just intellectually exciting but critical to human existence.
- Second, rapid advances in NASA Earth observing capabilities, coupled with revolutionary advances in information technology, have positioned us for an extraordinary new era in Earth science research—one in which we can quantitatively understand and predict the Earth *as a system,* with the temporal

and spatial fidelity needed by decision-makers at many levels of our society: local, regional, and global. This will lead directly to major societal benefits including:

- improved national security
- better weather forecasts and warnings
- more targeted climate outlooks
- better management of natural resources including water, agriculture, and energy
- more effective mitigation of natural disasters such as drought, floods, landslides, and volcanic eruptions.

- Third, the importance of Earth science and the central role of NASA in this field argue for careful, thorough, and deliberative assessment to inform program planning, especially when major changes are being considered. The current pace of budgetary and program change in NASA is inconsistent with such an approach and could result in irrevocable damage to programs and scientific teams that have taken decades and billions of tax dollars to build.

I fully understand that NASA faces many difficult choices arising from the pursuit of ambitious goals in a period of national budget constraints. However, I believe it important to proceed carefully when making decisions regarding important national assets and programs such as those represented within the NASA Earth Science effort.

A. The Importance of Earth Science and NASA's Role

It is clear after decades of pioneering satellite observations that Earth is a system of tightly coupled parts that interact in complex ways to produce the whole. The study of such interactions has become known as Earth system science, and has led to numerous insights about how the Earth functions and how it is evolving and changing over time. To understand how the atmosphere supports and protects life, for example, one must appreciate the complex and tightly coupled circulation dynamics, chemistry, interactions with the oceans, ice, biosphere, and land surface: all driven by solar radiation. And today, the natural system is clearly susceptible to changes due to human activity, creating still more complexity and variability over many scales of time and space. In any foreseeable future, we will have to understand this "system of systems" in order to help create, maintain, safeguard, and guide human societies. Earth system science, based on comprehensive and accurate ground- and space-based observations, is the toolkit that enables such investigation. Furthermore, the manner in which we explore other worlds will be informed by the understanding of our own.

Slide 1. Fully sunlit Earth photographed by Apollo 17 astronauts on route to the Moon.

For me personally, this "blue marble" photograph taken over 30 years ago by Apollo 17 astronauts on the way to the Moon perfectly represents this complex system. You have all seen this incredible picture hundreds of times in advertisements, reports and public media. It is perhaps one of the most significant, but under-sung, societal icons we possess. At NCAR, it is featured in a wall mural.

There are many ways to illustrate the importance of NASA's role in supporting Earth system science in the U.S. In sheer budgetary terms, NASA is the single largest environmental science program supported by the Federal Government. The widely respected budget analyses of the American Association for the Advancement of Science (AAAS) indicate that NASA provided 34 percent of the total funding for the environmental sciences in 2004. Much of this spending is devoted to the design, development, and operation of scientific instruments, the spacecraft that carry them, and the data systems required to process, analyze, archive, and distribute data to the scientific community and other users. But it should also be remembered that NASA provides significant resources to university investigators through the research and analysis component of its program.

In fact, leaving spacecraft and data system costs aside, AAAS analyses show that NASA was the third largest provider of competitively awarded extramural funding for the university environmental science community in 2004, trailing only the National Science Foundation and the National Institutes of Health. Even small reductions in the NASA program have large effects in the university community. This matters both because research and analysis is the process by which useful information is derived from remote sensing systems, and because university-based research activities provide the human capital (undergraduates, graduate students, young researchers and engineers) that underpins the entire space program. The effects of funding perturbations reach far beyond the year in which they occur. The design and development of an Earth observation satellite takes a decade or more, and keeping young scientists and engineers engaged in such work requires some degree of steady ongoing support.

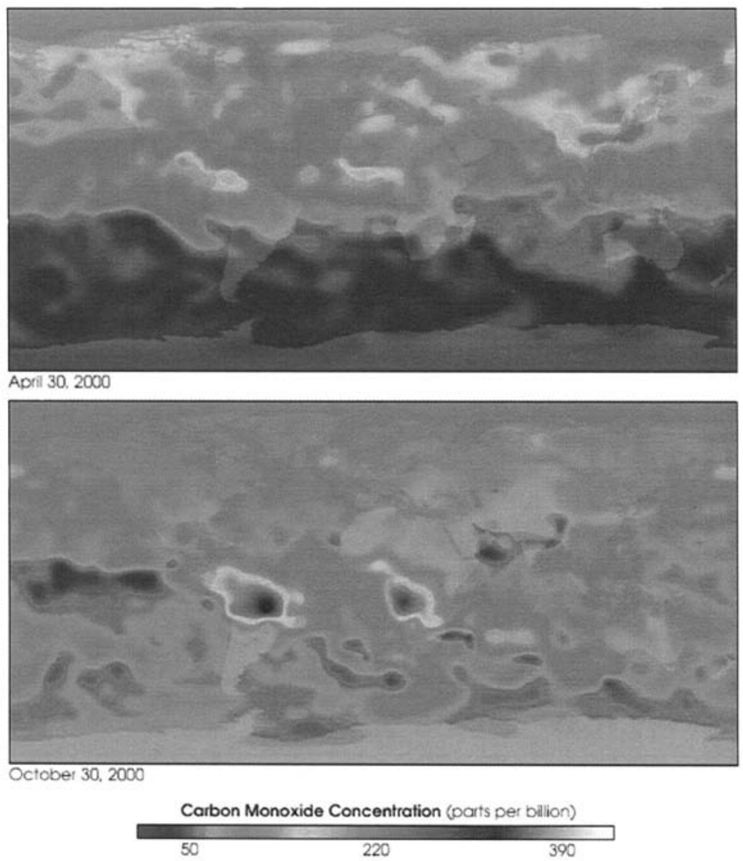
Another way of showing NASA's importance to this field is by looking at what has been accomplished. The scientific and practical results from NASA's Earth science program are much too extensive for me to catalogue here, but two examples can illustrate the unique contribution that NASA has made to our understanding of the Earth's atmosphere and its variations.

Example 1: Ozone depletions

The first example is probably well known to you. The ozone "holes" in the Antarctic and Arctic were monitored from space by various NASA satellite systems, including the Total Ozone Mapping Spectrometer (TOMS). The diagnosis of the physical and chemical mechanisms responsible for these dangerous changes to our protective ozone shield was made possible by the combination of observations, modeling, and theory supported by NASA. In fact, it was a NASA high-altitude aircraft that made the "smoking gun" measurements that convinced the scientific and policy communities that chlorine compounds produced by various human activities were centrally responsible for the observed ozone loss. Following these observations, international protocols were put in place that are beginning to ameliorate the global-scale ozone loss. The TOMS instrument has provided an ongoing source of data that permits us to track the level of ozone in the stratosphere, the annual opening and closing of the "ozone hole," and how this phenomenon is changing over time. These continuing measurements and analyses and the effective regulatory response have led, among other things, to a reduction in projected deaths from skin cancer worldwide.

Example 2: Air Pollution Observations

Last week, President Bush mentioned proposed rules to limit air pollution from coal-fired power plants. Air pollution is clearly an important concern. NASA has played a major role in the development of new technologies that can monitor the sources and circulation patterns of air pollution globally. It is another tremendous story of science serving society through innovation. In this case, through an international collaboration, NASA deployed a one-of-a-kind instrument designed to observe global carbon monoxide and its transport from the NASA Terra spacecraft. These animations show the first global observations of air pollution. Sources of carbon monoxide include industrial processes (see, for example, source regions in the Pacific Rim) and fires (for example in Amazonia). These global-scale data from space have helped change our understanding of the relationship between pollution and air quality—we now know that pollution is not solely or even primarily a local or regional problem. California's air quality is influenced by industrial activity in Asia, and Europe's air quality is influenced by activities here in America.



Slide 2. Global measurements of air pollution from NASA Terra satellite. Courtesy NASA/GSFC, University of Toronto and NCAR

From such pioneering work, operational systems can now be designed to observe pollution events, the global distribution of chemicals and particulate matter in the atmosphere, and the ways in which these substances interact and affect the ability of the atmosphere to sustain life—such a system will undoubtedly underpin future efforts to understand, monitor, and manage air quality globally. Without NASA's commitment to innovation in the Earth sciences, it is hard to believe that such an incredible new capability would be available today.

B. The Promise of Earth Observations in the Next Decade

The achievements of the last several decades have laid the foundation for an unprecedented era of discovery and innovation in Earth system science. Advances in observing technologies have been accompanied by vast improvements in computing and data processing. When the Earth Observing System satellites were being designed, processing and archiving the data was a central challenge. The Terra satellite produces about 194 gigabytes of raw data per day, which seemed a daunting prospect at the time of its definition. Now laptop memories are measured in gigabytes, students can work with remote sensing data sets on their laptops, and a large data center like NCAR increases our data holdings by about 1,000 gigabytes per day. The next generation of high performance computing systems, which will be deployed during the next five years or so, will be petascale systems, meaning that they will be able to process millions of gigabytes of data. The ongoing revolution in information technology has provided us with capabilities we could hardly conceive of when the current generation of Earth observing satellites was being developed. We have just begun to take advantage of the synergies between these technological areas. The U.S., through NASA, is uniquely positioned to take advantage of this technological opportunity.

Example 3: Weather Forecasting

Weather forecasting in the Southern Hemisphere has been dramatically improved through NASA's contributions, and this experience illustrates the power of remote sensing for further global improvements in weather prediction. The lack of surface-based data in the Southern Hemisphere once meant that predictive skill lagged considerably behind that achieved in the Northern Hemisphere. The improvement in the accuracy of Southern Hemisphere weather forecasting is well documented and almost entirely due to the increased use of remote-sensing data. But improvements in the quality of satellite data were not sufficient. Improvements in data assimilation—a family of techniques for integrating observational results into predictive models—were also necessary. The combination has resulted in rapid improvement in Southern Hemisphere forecasting, which is now nearly equal to that in northern regions. Data assimilation capabilities continue to advance rapidly.

One can now easily conceive of forecast systems that will fuse data from satellites, ground-based systems, databases, and models to provide predictions with unprecedented detail and accuracy—perhaps reaching natural limits of predictability. A new generation of weather forecast models with cloud-resolving spatial resolution is coming online, and these models show significant promise for improving forecast skills across the board. Use of new NASA remote sensing data from upcoming missions such as Calipso (Cloud-Aerosol and Infrared Pathfinder Satellite) and CloudSat will be essential to fully validate and tune these new capabilities which will serve the Nation in providing improved hurricane and severe storm prediction, and in the development of numerous decision support systems reliant on state-of-the-art numerical weather prediction capabilities.

Example 4: Earth System Models

Data from NASA missions are central to constructing more comprehensive and detailed models that will more realistically represent the complexity of the Earth system. Cloud observations from MODIS (the Moderate Resolution Imaging Spectroradiometer) and precipitation measurements from GPM (the Global Precipitation Mission), for example, are critical to improving the representation of clouds and the water cycle in such models. Observations from MODIS and Landsat are fundamental to the development of more sophisticated representation of marine and terrestrial ecosystems and atmosphere-land surface interactions. The inclusion of this detail will help in the creation of true Earth system models that will enable detailed investigation of the interactions of Earth system processes and multiple environmental stresses within physically consistent simulated systems.

In general terms, Earth system observations represent the only means of validating Earth system model predictions. Our confidence in short-term, regional-scale weather predictions is based on how closely they match observed regional conditions. Assessing the performance of global-scale, longer-term model predictions likewise depends on comparing model results with observational records. Scientific confidence in the ability of general circulation models to represent Earth's climate has been greatly enhanced by comparing model results for the last century with the observational records from that period. At the same time, the sparse and uneven nature of past observational records is an ongoing source of uncertainty in the evaluation of model results. The existence of much more comprehensive and consistent global measurements from space—such as the data from the NASA Terra, Aqua, and Aura satellites—is a giant step forward in this regard, and, if maintained, will enable much more rigorous evaluation of model performance in the future.

In summary, Earth system models, with increasing temporal and spatial resolutions and validated predictive capabilities, will be used by industry and governmental decision-makers across a host of domains into the foreseeable future. This knowledge base will drive new economies and efficiencies within our society. I believe that requirements flowing from the needs and capabilities of sophisticated Earth system models will be very useful for NASA in developing strategic roadmaps for future missions.

C. The Importance of Careful Planning

The central role of NASA in supporting Earth system science, the demonstrated success and impact of previous and current NASA missions, and the promise of continued advances in scientific understanding and societal benefits all argue for a careful, analytical approach to major modifications in the NASA Earth science program.

As noted above, the development of space systems is a time-consuming and difficult process. Today's actions and plans will have long-term consequences for our nation's capabilities in this area.

The link between plans and actions is one of the most important points I want to address today. From the outside, the interagency planning process seems to be experiencing substantial difficulties in maintaining this link. The NASA Earth science program is part of two major Presidential initiatives, the Climate Change Science Program (CCSP) and the Global Earth Observation System of Systems (GEOSS). With regard to the CCSP, it is not apparent that the strategies and plans developed through the interagency process are having much impact on NASA decision-making. In January 2004, then-Administrator of NASA, Sean O'Keefe, called for acceleration of the NASA Glory mission because of the direct relevance of the mission to understanding the roles of aerosols in the climate system, which is one of the highest-priority science questions defined in the CCSP research strategy. NASA is now proposing cancellation of the mission. As I have emphasized throughout this testimony, the progress of and benefits from Earth system science research are contingent upon close coordination between research, modeling, and observations. The close coordination of program planning among the agencies that support these activities is also a necessity. This coordination currently appears to be fragile.

The effect of significant redirections in NASA and reduction in NASA's Earth science effort are equally worrisome in the case of the Administration's GEOSS initiative, which is focused on improving the international coordination of environmental observing systems. Both NASA and NOAA satellite programs are vital to this effort. The science community is very supportive of the GEOSS concept and goals. There are over 100 space-based remote-sensing systems that are either operating or planned by various nations for the next decade. Collaboration among space systems, between space- and ground-based systems, and between suppliers and users of observational data is critical to avoiding duplication of effort and to getting the most out of the investments in observing technology. The tragic example of the Indian Ocean Tsunami demonstrates the need for such coordination. The tsunami was detected and observed before hitting land, but the absence of effective communication links prevented warnings from reaching those who needed them in time. A functioning GEOSS could lead to major improvements in the rapid availability of data and warnings, and the U.S. is right to make development of such a system a priority. But U.S. credibility and leadership of this initiative will be called into question if our nation is unable or unwilling to coordinate and maintain the U.S. programs that make up the core of our proposed contribution.

D. Answers to Questions Posed by the Committee

My testimony to this point has outlined my views on a series of key issues for the NASA Earth science program. Much of the text found above is relevant to consideration of the specific questions posed by the Committee in its letter of invitation. In this section, I provide more direct answers to these questions to the extent possible and appropriate.

How should NASA prioritize currently planned and future missions? What criteria should NASA use in doing so?

I believe that NASA should work with the scientific and technical community and its partner agencies to define a NASA Earth science plan that is fully compatible with the overall CCSP and GEOSS science strategies. In my view, the interaction with the scientific and technical community should include both input from and review by the National Research Council (NRC) and direct interaction with the strong national community of Earth science investigators and the aerospace industry who are very familiar with NASA capabilities and developing technological opportunities. Competitive peer review processes should be used appropriately in assessing the merit of competing approaches and in key decision-making. I believe NASA should also find a means of involving users and potential users of NASA-generated data in this process, perhaps through public comment periods or a series of workshops. Sufficient time should be allotted to this process for a careful and deliberative evaluation of options. This science plan should then guide the process of setting mission priorities.

Defining criteria to use in comparing and deciding upon potential missions would be an important part of this planning exercise. I would recommend consideration of a set of criteria that include:

- compatibility with science priorities in the CCSP and GEOSS science plans
- potential scientific return from mission
- technological risk
- direct and indirect societal benefits
- cost.

I believe that the decadal planning activity underway at the NRC in response to a request from NASA and NOAA is a valuable step in this process.

What are the highest priority unaddressed or unanswered questions in Earth science observations from space?

I believe this question is most appropriately addressed through the community process suggested above. There are many important Earth science questions, and prioritizing among them is best done in a deliberative and transparent process that involves extensive input from and discussion by the science community. I would personally cite soil moisture, three-dimensional cloud characteristics, global vector tropospheric winds, pollutant characteristics and transport, carbon fluxes, and aerosol distributions as all high priority measurements to make on a global scale.

What have been the most important contributions to society that have come from NASA Earth sciences over the last decade (or two)?

NASA Earth science programs have played a key role in developing our understanding of the Earth as a coupled system of inter-related parts, and in the identification and documentation of a series of global-scale changes in the Earth's environment, including ozone depletion, land use and land cover change, loss of biodiversity, and climate change. Other examples of societal contributions include improved weather forecasting, improved understanding of the large-scale climate variations, such as the El Niño-Southern Oscillation and the North Atlantic Oscillation that alter seasonal patterns of rainfall, and improved understanding of the status of and changes in marine and terrestrial ecosystems that contributes to more effective management of natural resources.

What future benefits to the Nation (societal applications) are possible that NASA Earth sciences could provide? What gaps in our knowledge must we fill before those future benefits are possible?

In a broad sense, NASA Earth science activities are part of developing a global Earth information system that can provide ongoing and accurate information about the status of and changes in the atmosphere, oceans, and marine and terrestrial ecosystems that sustain life, including the impact of human activities. The continued development of observation systems, sophisticated Earth system models, data assimilation methods, and information technologies holds the promise of much improved predictions of weather and climate variations and much more effective prediction and warning of natural hazards. Much has already been accomplished to lay the groundwork for such a system, but many important questions remain. Some of the most important have to do with the functioning and human alteration of the Earth's carbon, nitrogen, and water cycles, and how these cycles interact; the regional manifestation of global scale climate change; and the reactions of ecosystems to simultaneous multiple stresses.

Summary

In closing, I hope that my short list of examples suffices to emphasize the fact that it is not possible to conceive of a vigorous and healthy Earth system science effort in the United States without a strong ongoing NASA program. The scientific community is in the initial stages of a knowledge revolution enabled by the vast increases in the capabilities of, and synergy between, observation and information technologies. The advances in Earth system science that are being enabled by these capabilities are critical for understanding the Earth system and how it is changing. Such understanding is an important contribution to natural resource management, natural-hazard mitigation, and sustainable economic growth. I understand that NASA faces many difficult choices arising from pursuit of ambitious goals in a period of budget constraints, but I urge you to take account of the unique and central role of NASA observing programs in our nation's climate, weather, and Earth system science efforts as you oversee development of the plans and strategies that will guide NASA in the coming decade and beyond.

BIOGRAPHY FOR TIMOTHY L. KILLEEN

Director, National Center for Atmospheric Research; President-Elect, American Geophysical Union

Education

B.S. Honors 1st Class (Physics), University College London, 1972

Ph.D. (Atomic and Molecular Physics), University College London, 1975

Professional Experience

1972–1975 Research Student, University College London
1975–1978 Research Assistant, University College London
1978–1979 Postdoctoral Scholar, University of Michigan
1979–1984 Assistant Research Scientist, University of Michigan
1984–1987 Associate Research Scientist, University of Michigan
1988–1992 Affiliate Scientist, National Center for Atmospheric Research
1987–1990 Associate Professor of Atmospheric, Oceanic and Space Sciences, University of Michigan
1992 Visiting Senior Scientist, NASA Goddard Space Flight Center
1990–2000 Professor of Atmospheric, Oceanic and Space Sciences, University of Michigan
1993–1998 Director, Space Physics Research Laboratory, University of Michigan
1997–2000 Director, Global Change Laboratory, University of Michigan
1997–2000 Associate Vice President for Research, University of Michigan
2000–Present Director, National Center for Atmospheric Research and Senior Scientist, High Altitude Observatory, National Center for Atmospheric Research

Honors and Awards

NASA Achievement Award, Dynamics Explorer Spacecraft, NASA, 1985
Excellence in Research Award, University of Michigan, College of Engineering, 1993
Excellence in Teaching Award, University of Michigan, Department of Atmospheric, Oceanic and Space Sciences, 1995
NASA Achievement Award, Polar Spacecraft, NASA, 1998
Excellence in Teaching Award, University of Michigan, College of Engineering, 2000
AMS Fellow, 2005

Professional Affiliations

American Geophysical Union, President-Elect
American Meteorological Society, Fellow
American Association for the Advancement of Science

Professional Activities

Co-Chair, NASA Sun-Solar Systems Connections Roadmap, 2005
Principal Investigator, NASA TIMED Doppler Interferometer Investigation

Chairman BOEHLERT. Thank you very much, Dr. Killeen.
Dr. Solomon.

STATEMENT OF DR. SEAN C. SOLOMON, DIRECTOR, DEPARTMENT OF TERRESTRIAL MAGNETISM, CARNEGIE INSTITUTION OF WASHINGTON

Dr. SOLOMON. Thank you, Chairman Boehlert, Ranking Member Gordon, and Committee Members. I am very pleased to be with you today.

I am both an Earth scientist and a planetary scientist. I am a former President of the American Geophysical Union, and I am a principal investigator for one of NASA's missions to explore another planet.

Five years ago, I was asked by Ghassem Asrar, in this audience, to chair a working group to guide the science community in the development of a long-term vision for solid Earth science at NASA. And over two years, our group deliberated. We gathered advice, and in 2002, we published our recommendations. That effort of ours served as a microcosm for the Earth science decadal survey indeed for the challenge NASA now faces as it integrates top priorities across all of its programs.

Today, I would like to summarize the criteria that our group used to prepare that strategy, the most important questions we felt should guide NASA's programs and solid Earth science and most critical mission opportunities that our group recommended NASA pursue.

The surface of the Earth, of course, is where we live. Though largely solid, the interior of the Earth is far from static. The Earth's internal motions and interactions of the solid Earth with the atmosphere and the hydrosphere and the oceans continually change our planet's surface. And some of those changes occur very slowly, but some are, indeed, catastrophic: earthquakes, volcanic eruptions, landslides, floods, tsunamis, and other natural disasters.

If I could have the first view graph.

We understand the workings of the Earth, particularly the solid Earth, are linked through the notion of plate tectonics that the outer layer of the Earth is divided into rigid plates that are in relative motion and interact primarily at their boundaries, where earthquakes, volcanoes, and mountains are concentrated. We have such boundaries in California and Oregon and Washington and Alaska.

NASA's critical contribution to plate tectonics was to provide the first direct measurements of the motions of the plates through space geodata techniques. Research frontiers now are focused on exactly what is happening at the plate boundaries, what are the governing processes, and how does the solid Earth interact with the rest of the Earth system.

Our working group developed four criteria to select among future programs. A question to be addressed by NASA's programs should be of fundamental scientific importance, criteria number one. It should have a strong implication for society, number two. It should be amenable to substantial progress through new observations, number three. And there should be unique contributions that NASA could provide.

With these criteria, the working group identified six grand challenges, questions of highest priority, in the area of fault zones, landform change, sea level change, volcanic activity, internal dynamics, and the Earth's dynamic magnetic field.

Next slide, please.

In the near-term, the highest priority new mission that our group recommended for solid Earth science is a satellite dedicated to Interferometric Synthetic Aperture Radar, also known as InSAR. Such a mission, depicted in this animation flying over southern California, is technically feasible and addresses five of the six grand challenges for the solid Earth, and it is a critical element of the EarthScope project in partnership with the National Science Foundation and the U.S. Geological Survey. The mission will open the globe to new measurements of surface movements in earthquake zones, such as depicted here.

And on the next slide.

It would provide critical observations as well as other areas, such as active volcanic centers. What you see are four volcanic areas in South America thought to be inactive until InSAR observations showed that they were, in fact, inflating, as you see here in these Interferograms. But these volcanoes could have been in Oregon or Washington or Alaska, for that matter. InSAR, as well, can address that movements of the Earth's major ice sheets, coastal zones, areas susceptible to flood or landslides, and can reveal the underlying processes as well as provide a basis for hazard mitigation and response.

Of course, the recommendations of our working group are for the solid Earth component of the Earth system, and those must be integrated into the broader spectrum of NASA programs for all of Earth sciences.

But it is important, as I think this committee recognizes on the basis of the opening remarks, that our nation's space agency, as it carries out its many missions of exploration, does not lose sight of the special role that it can play in unraveling the mysteries of our own planet.

For the foreseeable future, ladies and gentlemen, the Earth is our only home. We owe it to our children and theirs to understand how to live here to the betterment of all.

Thank you.

[The prepared statement of Dr. Solomon follows:]

PREPARED STATEMENT OF SEAN C. SOLOMON

Thank you, Mr. Chairman, Ranking Minority Member, and Members of the House Science Committee. I am pleased to join you today to comment on NASA's programs in Earth science.

By way of introduction, I am both an Earth scientist and a planetary scientist. I am the Director of the Department of Terrestrial Magnetism at the Carnegie Institution of Washington, a former President of the American Geophysical Union—with more than 40,000 members the world's largest professional society in the Earth sciences, and the Principal Investigator for one of NASA's missions in solar system exploration.

First, let me begin by affirming my conviction that NASA has a continuing, strong role to play in the study of our planet. As the lead federal agency for technical innovation in space, with a clear charter for advancing basic knowledge of how this planet operates and for applying that knowledge to address problems of substantial societal importance, NASA can contribute to an understanding of the Earth and its workings in unique and fundamental ways. As this committee has expressed on many occasions, NASA's responsibilities in the Earth sciences are worthy of sustained national support.

Second, I applaud the Earth science community for undertaking a decadal survey of Earth science and applications from space. This survey, co-chaired by Dr. Moore and operated under the aegis of the National Academy of Sciences and the National Research Council, is long overdue. Like the decadal surveys that the astronomy community has produced for the last four decades and the decadal survey that the solar system exploration community published in 2002, this decadal survey for Earth science and applications from space will provide a rationale for the most important missions and programs that NASA should undertake in the coming decade, established on the basis of sufficient community input and set out with sufficient clarity so that the program is seen by all as both achievable in scope and compelling in vision.

In 2000 NASA's Associate Administrator for what was then the Office of Earth Science asked me to chair a working group "to guide the science community in the development of a recommended long-term vision and strategy from solid-Earth science at NASA." Over a period of two years that Solid Earth Science Working Group gathered advice from the community, and in 2002 we published our recommendations for a NASA program in solid-Earth science and applications for the coming quarter century. That effort served as a microcosm for the ongoing Earth science decadal survey and indeed for the challenge that NASA now faces as it integrates the most important objectives across all of its programs. Today I'd like to summarize the criteria that our working group used to prepare its strategy, the most important questions that our group felt should guide NASA's programs, and the most critical mission opportunities that our group recommended NASA should pursue to address those questions.

The surface of the Earth is where we live. Though largely solid, the interior of the Earth is far from static. The Earth's internal motions—and interactions of the solid Earth with the oceans, hydrosphere, and atmosphere—continually change the surface of our planet. Some of those changes progress at rates that seem nearly imperceptible over human lifetimes, but others concentrate catastrophically during earthquakes, volcanic eruptions, landslides, floods, tsunamis, and other natural disasters. Space offers a particularly special vantage point from which to study these phenomena, because of the broad, synoptic view and the global coverage afforded. Many of the workings of the solid Earth are linked by plate tectonics—the theory that the Earth's outer layer is divided into nearly rigid plates that are in relative motion and interact primarily at their boundaries. NASA's solid Earth program made a critical contribution to this theory, when space geodetic techniques provided the first direct measurements of plate motions previously inferred only from the geological record. The frontier research areas now are in understanding the details of deformation and volcanism near plate boundaries and the interaction of the solid Earth with the rest of the Earth system.

The Solid Earth Science Working Group utilized four criteria for selecting the most important questions in solid Earth science that could be addressed by NASA. First, the question should be of fundamental scientific importance. Second, the question should have strong implications for society. Third, the question should be amenable to substantial progress through new observations. And fourth, there should be unique contributions that NASA can make toward providing answers. These are quite general criteria that can be applied equally well across other NASA programs.

On the basis of these criteria, the working group identified six grand challenges, questions of the highest priority for NASA's solid Earth science program over the next 25 years:

1. What is the nature of deformation at plate boundaries, and what are the implications for earthquake hazards?
2. How do tectonics and climate interact to shape the Earth's surface and create natural hazards?
3. What are the interactions among ice masses, oceans, and the solid Earth and their implications for sea-level change?
4. How do magmatic systems evolve, and under what conditions do volcanoes erupt?
5. What are the dynamics of the mantle and crust, and how does the Earth's surface respond?
6. What are the dynamics of the Earth's magnetic field and its interactions with the Earth system?

Addressing these challenges involves leveraging partnerships with other NASA programs, with other federal agencies, and with international space agencies. Nonetheless, there are specific technological capabilities and orbital opportunities that only NASA can provide. The Solid Earth Science Working Group identified several observational strategies—each combining spaceborne and ground measurements with technological advances—where NASA should provide leadership: surface deformation, high-resolution measurements of topography and topographic change, variability in Earth's gravity and magnetic fields, imaging spectroscopy of Earth's changing surface, space geodetic networks and the International Terrestrial Reference Frame, and promising new techniques.

In the next several years, the highest-priority new mission for the solid Earth sciences is a satellite dedicated to Interferometric Synthetic Aperture Radar (InSAR). Such a mission is technically feasible today and addresses five of the six grand scientific challenges for the solid Earth. Operating at a frequency that can penetrate vegetative cover (L-band) and that has weekly access to any land area, such an InSAR system could measure surface displacements at the one mm/yr level over 50 km horizontal extents. InSAR satellites flown by European and Canadian space agencies have revealed the enormous potential of such a technology, but at radar frequencies and repeat viewing rates that are not optimum for understanding solid Earth phenomena. The recommended mission would open the globe to new observations of ongoing surface movements in major earthquake zones, at active volcanic centers, on the Earth's major ice sheets, along coastal zones, and in areas susceptible to floods and landslides. Such observations are likely to reveal diagnostics of the governing phenomena and can provide a regionally complete basis for disaster mitigation and response.

A NASA-led InSAR satellite is a critical element of the multi-agency EarthScope project, whose other elements—supported by the National Science Foundation—include seismometers, GPS sensors, strainmeters and a San Andreas Fault drilling project that together will address the nature of deformation within western North America as well as the structure and governing geological processes of the North American continent. A NASA InSAR satellite has also been requested by the U.S. Geological Survey to assist that agency with their ongoing assessment of seismic hazards and their mitigation within the United States.

The recommendations of the Solid Earth Science Working Group, of course, cover only one component of NASA's Earth science programs. The NRC decadal survey and NASA's own roadmapping activities, both currently underway, promise to provide a broader framework of recommended programs within which the component addressing the solid Earth and its interactions with the other elements of the Earth system will hold a natural place.

NASA is an agency that is carrying out a truly impressive range of human and robotic missions designed to explore our space environment, our planetary neighbors, and the entire cosmos. It is important as NASA carries out its many missions of exploration that we do not lose sight of the special role that only NASA can play in unraveling the mysteries of our own planet. For the foreseeable future, Earth is our only home, and we owe it to our children and theirs to understand how to live here to the betterment of all.

BIOGRAPHY FOR SEAN C. SOLOMON

Sean C. Solomon is the Director of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, a position he has held since 1992. He received his B.S. from Caltech in 1966 and his Ph.D. from MIT in 1971, after which he was a Professor of Geophysics at MIT for more than 20 years.

A seismologist, marine geophysicist, and planetary scientist, Solomon has worked on a wide range of problems in earthquake seismology, geodynamics, and the nature and evolution of the terrestrial planets. He served on science teams for NASA's Magellan mission to Venus and Mars Global Surveyor mission, and he is the Principal Investigator for NASA's MESSENGER mission now en route to orbit the planet Mercury.

From 2000 to 2002 Solomon chaired NASA's Solid Earth Science Working Group, which developed a long-term vision and strategy for solid-Earth science at NASA. Solomon earlier served on NASA's Space and Earth Science Advisory Committee, Solar System Exploration Subcommittee, and Earth System Science and Applications Advisory Committee. He also sat on the National Research Council's Space Science Board and chaired its Committee on Earth Sciences. He currently serves on NASA's Strategic Roadmap Committee for Earth Science and Applications from Space.

Solomon is a member of the National Academy of Sciences, a Fellow of the American Academy of Arts and Sciences, and a past President of the American Geophysical Union. A former Alfred P. Sloan Fellow and John Simon Guggenheim Fellow, he received the Arthur L. Day Prize from the National Academy of Sciences, the G.K. Gilbert Award from the Geological Society of America, the Harry H. Hess Medal from the American Geophysical Union, and NASA's Public Service Medal.

Chairman BOEHLERT. Thank you very much, Dr. Solomon.

Dr. McNutt.

STATEMENT OF DR. MARCIA McNUTT, PRESIDENT AND CEO, MONTEREY BAY AQUARIUM RESEARCH INSTITUTE

Dr. MCNUTT. Chairman Boehlert, Mr. Gordon, and distinguished Members of the Committee, thank you for this opportunity.

In my testimony today, I have chosen the tactic of simply answering your questions.

So let me go immediately to the first one, which is prioritizing future missions.

Chairman BOEHLERT. I might add that that is a novel approach.

Dr. MCNUTT. My own institution, the Monterey Bay Aquarium Research Institution, was founded and privately funded by David Packard to be a sort of NASA for the oceans, albeit on a much smaller scale. And like NASA, we constantly struggle at my institution to balance our various missions: exploration, societally-relevant research, technology development, and maintenance of time series.

In my written testimony, I have described how we manage to balance that diverse portfolio and many of the lessons we have learned along the way in doing so. I regret I don't have time to tell you all about that today. You can read about it, but frankly, it is not rocket science.

But let me pass on just one piece of advice from that portion of my response.

I have heard some argue that NASA could prioritize better if it handed out wholesale areas of NASA research, such as its Earth sciences program, to another civilian agency in order to focus its efforts. Severed from the root of the technology program that feeds it, innovation and the program would eventually wither, and it would die.

Okay. Next question.

You asked me to list some of NASA's greatest achievements in the Earth sciences from the past decade.

Certainly one of the most unexpected surprises was the contribution of satellite altimetry to so many areas of ocean sciences, such as measuring sea level, waves, currents, tides, air moisture, and for mapping the topography of the sea floor using its gravitational effect on the shape of the ocean's surface.

In my first figure, I show a dramatic comparison of our knowledge of the ocean floor topography in the South Pacific before, on top, and after the availability of satellite altimetry data.

I recall 14 years ago serving as Chief Scientist on an oceanographic expedition to the South Pacific. One night, we were steaming full-speed ahead when I called to the bridge from the main lab to say that based on my processing of the satellite altimetry data, we were headed straight towards a major undersea volcano with a very shallow summit. The mate on watch responded that nothing was marked on the navigational charts, but they agreed to slow down anyway. Less than 10 minutes later, I heard a seaman yell out in the moonlight: "Breakers at 100 yards and closing."

Second—next slide.

I will mention a different NASA development, and that is the instruments to measure ocean color to monitor the concentration of microscopic plants in the upper ocean. These small plants, called phytoplankton, are responsible for producing half of the oxygen we breathe, and they are the fundamental basis for nearly all of the oceanic food chain. This is an image of ocean color around the island of Tasmania, south of Australia, and it was acquired by NASA's SeaWiFS satellite in about one minute. It would have taken 10 years of nonstop operations of an oceanographic ship to acquire the same amount of information, and all of the dynamic details, such as the effect of eddies and currents on the distributions, would have been smeared out beyond recognition.

These satellite data have shown the changing productivity of the oceans in response to El Niño, reduction in polar ice extent, intensity of seasonal upwelling, and purposeful iron fertilization of the oceans.

Such monitoring of the biological changes in the ocean help us to understand the consequences of both natural and manmade changes to the physical and chemical environment in which these plants survive.

You also asked me to list the highest priority unanswered questions in Earth sciences that can be addressed from space.

If I could have the next slide.

Within the next decade, reconstruction of past climate records from sparse data have demonstrated that the Pacific Ocean temperature and productivity of fisheries all change in lock step to a thermal rhythm that waxes and wanes over decadal time periods. This temperature variation, which is called the Pacific Decadal Oscillation, or PDO, involves temperature changes of one to two degrees. That is it. The figure shows that the "cool" phase of the PDO ruled the Pacific in the early 1960s and it corresponded to the crash in the sardine fishery in my own hometown, Monterey, California.

Landings of sardines fell from 3.6 million metric tons in the 1930s to less than 10,000 metric tons by 1965. During that same time, when the sardine fishery was crashing, the anchovy fishery offshore Peru became the largest single-species fishery in the world. In the mid-1970s, the regime shifted, and the Peruvian anchovy fishery, in turn, crashed.

The most recent regime shift, which coincided with the 1997–1998 El Niño, was captured by a number of satellite sensors. Seal level, as measured by altimetry, ocean temperature, and ocean plant production, as measured by ocean colored, all shifted together back into the "cool," or the anchovy-rich phase.

So what forces caused the shift? What rhythms govern the time scale? We don't know. But much is at stake. The numbers of seabirds in Hawaii, Monarch butterflies in Mexico, and salmon in Oregon all appear to vary at the pace of the PDO.

We have only captured one shift with high-quality satellite records, but the hope is that with patience, we will understand how the system works and hopefully avoid another fisheries crash, like the one that devastated Monterey.

In your last question, you asked me about the future of NASA's contributions to Earth sciences.

Well, there are exciting couplings emerging among the physical, chemical, and biological aspects of the ocean, that point to a planetary metabolism that is best observed and most efficiently monitored from space. I have no doubt that upon further investigation, we will find that many changes in the land-based biosphere are also marching in step to that rhythm.

Understanding exactly what will happen before it happens is clearly a powerful position to be in, because it enables to take actions that benefit from the regime shift as opposed to remaining in those that suffer from it.

Thank you very much for this opportunity to speak to you on these critically important issues.

[The prepared statement of Dr. McNutt follows:]

PREPARED STATEMENT OF MARCIA MCNUTT

Chairman Boehlert, Ranking Minority Member, and Members of the Committee:

Thank you for this opportunity to speak to you this morning on the issue of NASA's past, present, and future outlook for making contributions to the Nation and the world in the area of Earth Sciences. My name is Marcia McNutt, and I currently serve as the President and CEO of the Monterey Bay Aquarium Research Institute, better known as MBARI. I am a Past President of the American Geophysical Union, the largest professional society serving the geosciences. It has been more than a decade since my own research was funded by NASA, and NASA contributes only one percent of my institution's annual operating budget. I mention these facts merely to make the point that I have no financial incentive to provide you with anything other than my best advice.

Prioritizing Missions

First, you ask about prioritizing future missions. My own institution, MBARI, was founded and privately funded by David Packard to be a "NASA for the oceans," albeit on a much smaller scale. Like NASA, we constantly struggle at MBARI to balance our various missions. We must continue to explore the ocean in new dimensions while still conducting societally-relevant ocean research. We must apply emerging technologies to next-generation ocean systems without abandoning critical long-term time series.

There is no magic formula for making these hard choices. Tackling societally-relevant problems with near-term payback justifies the investment to today's taxpayers, while exploration lays the foundation for the societally-relevant research of the future and entrains the next generation. NASA is the only civilian agency that has the required capacity, tradition, and track record to vigorously pursue the technology development that will fuel tomorrow's discoveries. But at the same time, NASA has an obligation to maintain certain critical time series as long as the societal relevance is high, the rate of discoveries continues unabated, and the incremental cost is low as compared with the cumulative prior investment. Unlike most S&T products, the value of time series only increases with age since inception. I have heard some argue that NASA could hand off wholesale areas of NASA research, such as the Earth sciences program, to another civilian agency in order to focus its efforts. Severed from the root of the technology program that feeds it, innovation in the program would eventually wither and die.

So how do we at MBARI maintain a balanced portfolio given these different, but essential missions? First, we determine what rough percentage of resources should be reserved for each mission area, and enforce the quota vigorously. The quotas are set so as to maintain critical mass and set a reasonable level of expectation in each program area such that the associated researchers can make long-term plans. If our overall budget grows, everything grows proportionally. If the overall budget shrinks, everything shrinks proportionally. Within those mission areas, projects compete with other like projects, but it would be unfair to pit exploration, for example, versus societally-relevant research because different criteria need to be used to measure their respective values.

Like NASA, my MBARI also undertakes high risk, long-lead time projects. Through experience, we have learned a few important lessons:

1. **Protect the rest of the research portfolio from being consumed by the large, long-term project by respecting the percentage quotas.** It is the rest of the research portfolio that helps to manage risk, retain balance, and nurture the seeds of the next big project.
2. **Structure the big project so that it provides science return at many incremental steps along the way.** We didn't have to discover this for ourselves at MBARI, because the Earth sciences community had already learned this lesson the hard way through the Mohole Project in the 1960s. The initial objective was to drill through the ocean crust into the underlying mantle rocks. The project proved to be so technically challenging and so mired in management missteps that after many years and many wasted millions of

dollars it took an act of Congress to kill it. Out of the ashes of the Mohole Project arose the Deep Sea Drilling Project, now known as the Integrated Ocean Drilling Program. The Mohole's successor program had much more modest and achievable goals that kept the scientific community excited and engaged as remarkable discoveries were made in every ocean basin. The seafloor spreading hypothesis was confirmed. Climate records extending back more than 100 million years were recovered. And now, nearly 50 years after the Mohole Project was first conceived, we are finally on the brink of drilling into the oceanic upper mantle!

3. **If the project is really big, get lots of help.** We get help from institutions like Woods Hole and JPL for our biggest projects. The drilling program discussed above involved 23 different nations and is, in fact, held up as a model for international scientific cooperation.
4. **Get realistic cost and schedule estimates for the big project before undertaking it, including an assessment of the value of what will need to fall off your agenda if you pursue it.** And then make sure you can afford it. If you have structured the big project for incremental science return (see #2 above), then it won't matter if you don't achieve your goal right away because the discoveries along the way will maintain the project's momentum, keep the research community engaged, and justify the investment.

NASA's Greatest Achievements in the Earth Sciences

You also asked me to list some of NASA's greatest achievements in the Earth Sciences from the past few decades. There are so many—the discovery of the ozone hole, the direct measurement of plate tectonic drift from space, the detection of post-seismic crustal deformation that influences the pattern of future earthquakes using Synthetic Aperture Radar, ... The list goes on. Knowing that you will be hearing from Drs. Solomon and Killeen on the accomplishments in the area of solid Earth and atmosphere, respectively, I'll concentrate on the oceans.

Certainly one of the most unexpected surprises was the contribution of satellite altimetry to so many areas of ocean sciences. NASA pioneered the technology for measuring sea surface height from 800 km altitude in space to 10 centimeter accuracy nearly 30 years ago. The technique was so successful for measuring sea level, waves, currents, tides, and air moisture, and for mapping the topography of seafloor using its gravitational effect on the shape of the ocean surface, that a number of other agencies both foreign and domestic launched follow-on altimeter missions. NASA continues to operate altimeters from space today, and each generation improves in its accuracy and scientific return.

Figure 1 shows one dramatic comparison of our knowledge of the ocean floor topography before and after the availability of satellite altimetry data. I recall 14 years ago serving as chief scientist on an oceanographic expedition to the South Pacific. One night we were steaming full speed ahead, when I called to the bridge from the main lab to say that based on my processing of the satellite altimetry data, we were headed straight towards a major undersea volcano that might have a very shallow summit. The mate on watch responded that nothing was marked on the navigational charts in the vicinity, but he agreed to slow down anyway. Less than 10 minutes later I heard a seaman yell out in the moonlight: "Breakers at 100 yards and closing!" Because the mate had already backed down on the engines, the ship was able to turn before crashing into the reef.

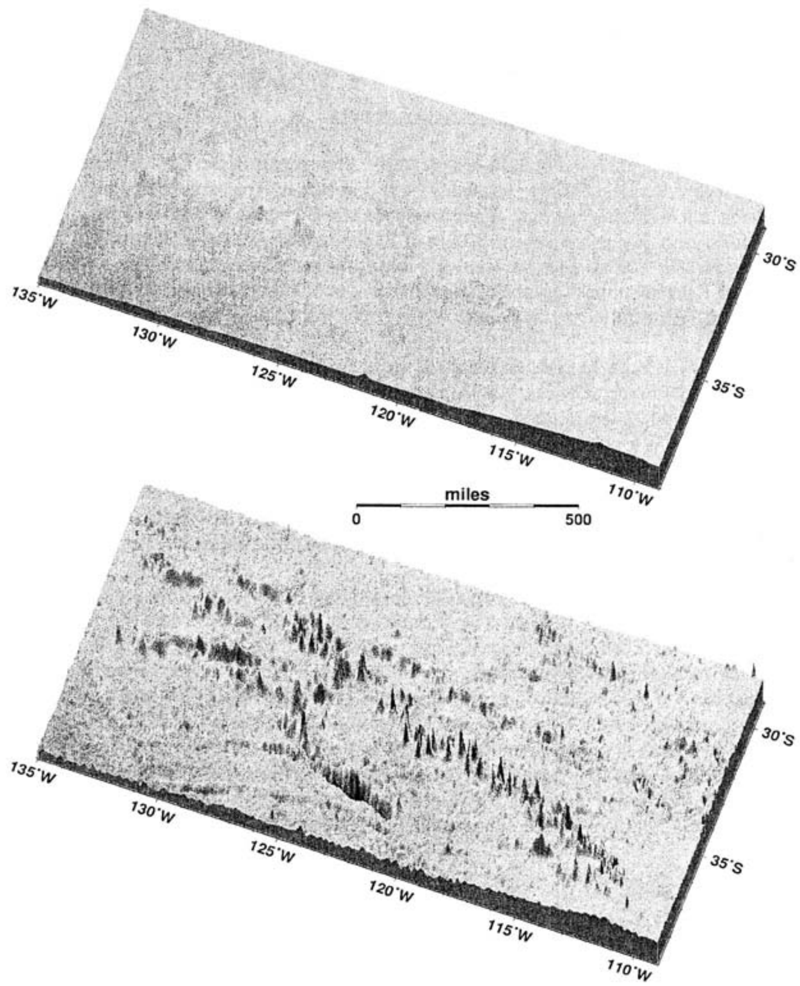


Figure 1. Comparison of our best available information on the bathymetry of the ocean basins in the South Pacific before (above) and after (below) the use of satellite altimetry to estimate the shape of the solid seafloor. These improved images have found many practical applications, such as providing safer navigation for ships and submarines, finding new productive fishing grounds, assessing volcanic and earthquake hazards, and improving general understanding of the geologic history and structure of the ocean basins. Source: http://www.ngdc.noaa.gov/mgg/image/seafloor.html

As a second, very different example, I will briefly mention NASA's development of instruments to measure ocean color to monitor the concentration of microscopic plants in the upper ocean. These small plants, called phytoplankton, are responsible for producing about half of the oxygen that we breathe and are the fundamental basis for nearly all of the oceanic food chain. One teaspoon of seawater can contain as many as a million of these fast-growing plants. NASA satellites have monitored the temporal changes in the concentrations of these minute plants from 700 km in space for a little more than two decades. This image of ocean color around Tasmania south of Australia was acquired by the SeaWIFS satellite in just about one minute.

It would have taken 10 years of non-stop operations of an oceanographic ship to acquire the same amount of information, and all of the dynamic details, such as the effect of eddies and currents on the distributions, would have been smeared out beyond recognition. These satellite data have shown the changing productivity of the oceans in response to El Niños, reduction in polar ice extent, intensity of seasonal upwelling, and purposeful iron fertilization of the oceans. Such monitoring of the biological changes in the ocean help us to understand the consequences of both natural and man-made changes to the physical and chemical environment in which these plants survive.

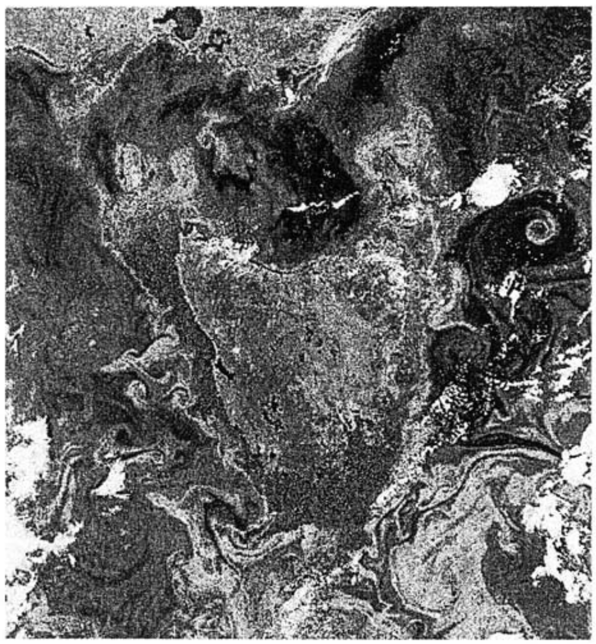


Figure 2. SeaWIFS imagine of chlorophyll concentrations in the surface waters around the island of Tasmania just south of Australia. Source: http://oceancolor.gsfc.nasa.gov/SeaWiFS/TEACHERS/sanctuary_2.html

Highest Priority Unanswered Questions

In your second question, you asked me to list the highest priority unanswered questions in Earth Sciences that can be addressed from space. Again, I will choose an ocean example. Within the last decade, reconstruction of past climate records from sparse data have demonstrated that the Pacific ocean temperature and productivity of fisheries all change in lock step to a climate rhythm that waxes and wanes over decadal time scales Figure 3). This temperature variation, called the Pacific Decadal Oscillation or PDO, involves temperature changes of just one to two degrees and has also been well correlated with changes in sea level recorded by satellite altimeters. The Figure below shows that the "cool" phase of the PDO that ruled the Pacific in the early 1960's corresponded to the crash in the sardine fishery in my own hometown, Monterey, CA. Landings of sardines fell from 3.6 million metric tons in the 1930's to less than 10,000 metric tons by 1965. During that same time, the anchovy fishery offshore Peru became the biggest single-species fishery in the world. In the mid-1970's, the regime shifted, and the Peruvian anchovy fishery crashed. The most recent regime shift which coincided with the 1997–98 El Niño was captured by a number of satellite sensors: sea level (as measured by altimetry), ocean temperature, and ocean plant production (as measured by ocean color) all shifted together back into the cool (anchovy dominated) phase. So what forces cause the shift? What rhythms govern the time scale? We don't know, and its long life span

(20–30 years between regime shifts) means that we must be patient. But much is at stake. The numbers of seabirds in Hawaii, monarch butterflies in Mexico, and salmon in Oregon all appear to vary at the pace of the PDO—despite the fact that the temperature variations are one to two degrees! We have only captured one shift with high-quality records, but the hope is that with patience we will understand how the system works, and hopefully avoid another fisheries crash like the one that devastated Monterey.

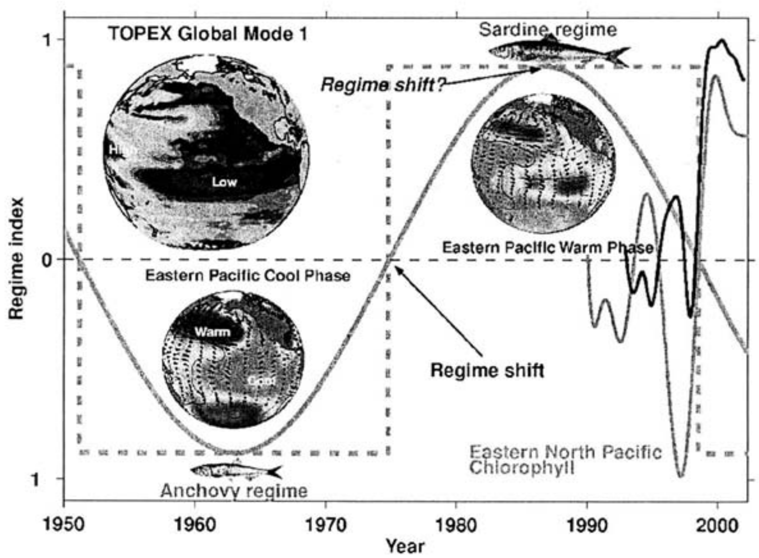


Figure 3. Illustration of the changing nature of the Pacific Decadal Oscillation (PDO). These variations of just one to two degrees in the Pacific ocean temperature pattern have a large effect on the productivity of fisheries. When the anchovy fishery off Peru in strong (the Eastern Pacific cool phase), the sardine fishery in Monterey is poor. Note the strong correlation between sea surface height from the TOPEX altimeter and the ocean temperature pattern as observed from space during the most recent cool phase. Even the microscopic plants in the upper ocean respond to the warm and cool phases. Figure published in Science (volume 299, pp. 219-221, 2003) and provided courtesy of Francisco Chavez, MBARI.

Future Prospects

In your fourth question, you asked me about the future of NASA's contributions to Earth Sciences. I hope that I have already made the point that there are exciting couplings emerging among the physical, chemical, and biological aspects of the ocean that point to a planetary metabolism that is best observed and most efficiently monitored from space. I have no doubt that upon further investigation, we will find that many changes in the land-based biosphere are also controlled by similar rhythms, just as scientists have been able to demonstrate the connection between the El Niño event in the eastern tropical Pacific and, for example, drought in South Africa. Understanding exactly what will happen before it happens is clearly a powerful position to be in, because it enables us to take actions that benefit from the regime shift, as opposed to those that suffer from it. I am personally very excited about the prospects of monitoring salinity directly from space, in order to get the second necessary component for understanding the thermo-haline circulation that transports so much of the planets' mass and energy. I see the potential for monitoring the planet's carbon cycle from space through both direct measurements and better modeling of the thermohaline circulation. For example, we estimate that the oceans take up a net 2,000 million metric tons of carbon dioxide from the atmosphere annually, but that number is the small difference between two very large numbers: 90,000 million tons of CO_2 taken up by ocean plants and other processes versus 88,000 million tons of CO_2 returned to the atmosphere from the ocean through the upwelling of deep ocean waters. Clearly our "balance of payments" (so to speak) in terms of the carbon budget is very sensitive to both the physical and biological states of the ocean, which in turn vary with both the El Niño and the PDO oscillations. There is so much to learn, and only when we have a better understanding of all of these cycles and where we are within them will we be able to make wise policies to protect and sustain our Earth environment.

Thank you very much for this opportunity to speak to you on these critically important issues.

BIOGRAPHY FOR MARCIA MCNUTT

Marcia McNutt is the President and CEO of the Monterey Bay Aquarium Research Institute (MBARI) in Moss Landing, California. MBARI is a nonprofit research laboratory funded by the David and Lucile Packard Foundation to develop and apply new technology for the exploration of the oceans.

McNutt is a native of Minneapolis, Minnesota, where she graduated class valedictorian from Northrop Collegiate School in 1970. In 1973, she received a BA degree in Physics, *summa cum laude,* Phi Beta Kappa, from Colorado College in Colorado Springs. As a National Science Foundation Graduate Fellow, she studied geophysics at Scripps Institution of Oceanography in La Jolla, California, where she earned a Ph.D. in Earth Sciences in 1978.

After a brief appointment at the University of Minnesota, she spent the next three years at the U.S. Geological Survey in Menlo Park, California, working on the problem of earthquake prediction. In 1982, she joined the faculty at MIT in Cambridge, Massachusetts. At MIT, she was appointed the Griswold Professor of Geophysics and served as Director of the Joint Program in Oceanography and Applied Ocean Science and Engineering, a cooperative graduate educational program between MIT and the Woods Hole Oceanographic Institution.

McNutt's research ranges from studies of ocean island volcanism in French Polynesia to continental break-up in the Western U.S. to uplift of the Tibet Plateau. She has participated in 15 major oceanographic expeditions, and served as chief scientist on more than half of those voyages. She has published 90 peer-reviewed scientific articles.

In 1997, McNutt took over the leadership at MBARI. McNutt has encouraged the institution to tackle the sort of research problems that traditionally have been difficult to support under federal grants and contracts, such as high-risk ventures, development efforts with long lead times between conception and scientific return, and interdisciplinary research. She has also encouraged her researchers to develop affordable technology for ocean exploration and observation that can be passed on to the larger oceanographic community.

McNutt's honors and awards include membership in the American Philosophical Society and the American Academy of Arts and Sciences. In 1985, she was awarded a Mary Ingraham Bunting Fellowship from Radcliffe College. She also holds honorary doctoral degrees from the University of Minnesota and from Colorado College. In 1988, McNutt won the Macelwane Award from the American Geophysical Union, presented for outstanding research by a young scientist. In 2003 she was honored as the Scientist of the Year from the ARCS Foundation. In 2004, she received the Outstanding Alumni Award from the University of California at San Diego. She is a fellow of the American Geophysical Union, the Geological Society of America, the American Association for the Advancement of Science, and the International Association of Geodesy.

McNutt served as President of the American Geophysical Union from 2000–2002. She also chaired the President's Panel on Ocean Exploration, convened by President Clinton to examine the possibility of initiating a major U.S. program in exploring the oceans. She currently serves on numerous evaluation and advisory boards for institutions such as the Monterey Bay Aquarium, Stanford University, Harvard University, *Science* Magazine, and Schlumberger.

Chairman BOEHLERT. And thank you for your direct response to our questions, but you left us with a bigger questions with your, "Breakers at 100 yards and closing," and then you went off in a new direction. I assume the ship did, too.

Dr. MCNUTT. The ship, because it had slowed down, was able to turn in time, and we missed the reef.

Chairman BOEHLERT. And that permitted you to be here with us today.

Dr. MCNUTT. Yes. Thank you.

Chairman BOEHLERT. You are welcome.

Dr. Williamson.

STATEMENT OF AND DR. RAY A. WILLIAMSON, RESEARCH PROFESSOR, SPACE POLICY INSTITUTE, THE GEORGE WASHINGTON UNIVERSITY

Dr. WILLIAMSON. Chairman Boehlert, Ranking Minority Member Gordon, Members of the Committee, it is a pleasure to be here today to testify on NASA's Earth science efforts and their impact on U.S. citizens.

For nearly 25 years, I have followed and analyzed the development of U.S. Earth science and applications capabilities. During that period, federal investments in Earth science research and technology have led to powerful methods for improving weather and climate forecasts, including advanced warnings of changing weather, damaging weather, transportation planning and monitoring, agricultural planning, energy efficiency, and other geographically- and environmentally-influenced activities.

Yet despite the substantial progress over the years, a lot more can and should be done. And it should be done to assure that the benefits of future Earth science research actually reach the American public. NASA's Earth science research is critical to that goal. It is a major national asset.

In recent research co-funded by NASA and NOAA, my colleagues and I have explored the scope and scale of social and economic benefits provided by NASA's Earth science research and by NOAA's applications of some of that research. We determined that realized benefits were quite substantial, but not well quantified. Nevertheless, all available studies indicate, with little doubt, that improved weather and climate forecasts have saved millions of dollars in property damage, prevented the loss of life from severe storms, and contributed millions or even billions of dollars to industrial efficiency.

Now other members of this panel have sited other examples of—many examples of Earth science research. I want to add one that is also—is on my list but hasn't been mentioned, and that is the significant science and technical support in the development of a $3.5 billion, that is yearly, satellite and aerial remote-sensing data and applications industry, which is now growing at a rate between nine and 14 percent per annum.

At present, as I have mentioned, we cannot draw quantitative conclusions about the total social and economic benefits of NASA's Earth science information. This means that benefit studies cannot yet be used with confidence to guide future investments in space systems. Since NASA is at the cutting edge of Earth science research in this country, it should focus more attention on this important subject in order to guide its future research.

Mr. Chairman, I see four major issues related to NASA's ability to support the country in Earth science research.

First, as has been mentioned, declining Earth science budgets and delayed or canceled Earth science missions.

Second, U.S. leadership in the international Global Earth Observation System of Systems. We initiated that effort nearly two years ago, and it stands to bring greater benefits than ever to the United States and to the world. Congress should support that leadership.

Three, the general lack of quantitative and qualitative data on the benefits of Earth science research. In other words, what are we buying with our dollars, and how much has it gotten us.

Four, insufficient attention to developing the methods and paths to NASA's—take NASA's research efforts into operations and to applications for end-users, in other words, the American public.

In summary, NASA's Earth science program has provided substantial benefits to the United States. I see several ways in which this committee could be especially helpful in assuring that the public actually reaps the benefits of this research.

One, eliminate the steady decline in the proportion of NASA's budget devoted to Earth science. NASA's Earth science program produces real benefits to the American public and should be maintained at a level that maintains strong U.S. leadership in Earth science research.

Two, provide additional resources to support U.S. leadership in the Global Earth Observation System of Systems.

Three, authorize NASA to direct a greater attention to the quantification of the benefits of Earth science research applications to America's industry and the public sector and the policy implications of those benefits.

Four, include an exploration of the issue of transition from Earth science research to useful applications in the Committee's next hearing related to Earth science and applications.

In the eyes of many, Earth science research is not nearly as sexy or as cutting-edge as exploration beyond Earth orbit. It doesn't get the headlines. It certainly doesn't command the same sort of public attention as the astounding results from the Hubble Telescope or the Cassini Mission to Saturn. Nevertheless, Earth science research truly does involve exciting new technological developments and may be, in the long run, vastly more important in direct impacts to the economy and the public welfare than these other examples.

Just imagine what our lives would be like if our Earth science and meteorological satellites all suddenly failed. It is hard to imagine. Tomorrow's weather would again become guesswork, and electricity would start to cost us more. Local and regional environmental trends would be next to impossible to determine and monitor, as we have heard. Ships in the North and South Atlantic would be vastly more susceptible to iceberg collisions, and other hazards, such as underground volcanoes. Even the security of our homeland would be lessened and our defense efforts hindered. It is not well understood, I think, how much of NASA's Earth science efforts have drifted in and supported our homeland security—or could support our homeland security and our defense applications.

In short, we would stand to lose the substantial benefits that we have already gained from Earth science research applications. Continued aggressive support of these R&D and operational efforts is an essential component of the future of the economy and security of our nation.

And I thank you, Mr. Chairman, for this opportunity to present my views on these issues.

[The prepared statement of Dr. Williamson follows:]

PREPARED STATEMENT OF RAY A. WILLIAMSON

Mr. Chairman, Members of the Committee, it is a pleasure to be here today to testify on NASA's Earth science efforts and their impact on U.S. citizens. This is an important and crucial subject in these days of increasingly tight federal budgets for science and the development of useful applications of science results. For nearly 25 years I have followed and analyzed the development of U.S. Earth science and applications capabilities, first for the Congressional Office of Technology Assessment and since 1995, as a Research Professor in the Space Policy Institute within The George Washington University.

During those two and a half decades, the United States has made dramatic progress in Earth science and applications. Investments in several geospatial technologies have contributed to the development of powerful methods for improving weather and climate forecasts (including advance warnings of severe weather), transportation planning and monitoring, agricultural planning, energy efficiency, and other geographically—and environmentally—influenced activities.

Whether through NASA, NOAA, the U.S. Geological Survey, or though university research funded by the National Science Foundation, the federal investment has been key to bringing the science and the resulting methods and technologies to a status that they can truly benefit not only the Federal Government including important defense and homeland security programs but also State and local authorities, the private sector, and especially the average citizen. Yet, despite the substantial progress over the years, a lot more can and should be done to make sure that the benefits of science research actually reach the American public.

Benefits of Earth Science Research

Mr. Chairman, among other things, your letter of invitation to testify in this hearing asked about past accomplishments from the NASA Earth science program and what future benefits can be expected. In a recent research project co-funded by NASA and NOAA, my colleagues at the Space Policy Institute and I explored the scope of social and economic benefits provided by NASA's current Earth science research and NOAA's applications of science results to weather and climate, and determined that in sum they were quite substantial. However, reliable estimates of the total of such benefits do not exist and the available socioeconomic studies focus on specific examples of benefits to particular industries, geographical areas, and types of storms or damage. All of the available studies indicate with little doubt that improved weather and climate forecasts have saved many millions of dollars in property damage, prevented the loss of life from severe storms, and contributed further millions of dollars to industrial efficiency.

Both NASA and NOAA have made substantial contributions to the development of more accurate, longer-term weather and climate forecasts. NASA has provided the lead in new instrumentation, new understanding of the basic chemistry, physics, and biology of Earth systems, and advances in modeling and data assimilation techniques. NOAA has provided long-term, routine observations focused on improving forecast models and other decision support tools directly benefiting the end user of weather and climate information. More specifically, benefits of NASA's Earth science research include, but are certainly not limited to:

1. A much deeper and broader scientific understanding of Earth systems and how they function, which in addition to contributing to general scientific knowledge, also provide the basis for applied use of this important knowledge;
2. Development of sophisticated satellite sensors capable of monitoring Earth systems for the benefit of U.S. citizens;
3. Significant scientific and technical support in the development of a $3.5 billion dollar satellite and aerial remote sensing data and applications industry that is now growing at a rate between nine and 14 percent per annum [1];
4. Data, models, and other decision support tools for weather and climate forecasts, including forecasts of damaging storms. Data from the TRMM satellite, for example, enable forecasts to predict hurricane paths and rainfall amounts much more accurately [2].

When we examined the economics and related benefits literature related to NASA's Earth science research for quantitative economic studies or value analysis, we found relatively few in-depth studies. Further, although most studies cited sizable benefits, each study was carried out using a different valuation methodology, or was focused on a narrow element of the industry under study. Taken together, these two factors mean that few quantitative conclusions can be drawn about the total social and economic benefits of NASA's Earth science information to U.S. industry and to Federal, State, and local government applications. This means that benefits studies cannot yet be used with confidence to guide future investments in space systems.

Yet our studies show that the supportable, qualitative benefits of Earth science research are quite high to nearly all sectors of industry and to the public sector. Since NASA is at the cutting edge of Earth science research in this country, it should focus more attention on this important subject in order to assist in guiding its future research agenda. This is not to say that expected practical benefits alone should determine NASA's future research agenda, since such an approach might stifle creative, breakthrough research efforts, but such benefits should play a role in the decision process when difficult decisions are being made among projects.

The Electric Energy Industry

In order to understand the range of issues surrounding the development of benefits estimates, we focused on the potential social and economic benefits to the electric energy industry of improved weather and climate forecasts and other information derived from a combination of satellite data and other weather information. This industry, on which the United States depends as a critical part of the infrastructure of economic growth and well being, relies deeply on accurate weather and climate forecasts to estimate its customers' future demand for electricity and the company's needed future fuel supplies. Because satellites operate either globally or over very large regions, they provide synoptic views of meteorological conditions over substantial portions of the globe that cannot be monitored cost-effectively from aircraft or ground stations. In fact, some 90 percent of the data now used in weather forecasts derive from satellite measurements.

Our study shows that electric utilities derive the greatest economic benefit from weather forecasts that are accurate over 2–4 days. Improved 7–10 day weather forecasts would also provide additional economic benefit for utilities.[3] The companies use monthly and seasonal weather forecasts for scheduling maintenance and for meeting EPA-set yearly emission allotments. Longer-term forecasts assist in planning for new power generation facilities.

The industry also depends on such forecasts for severe weather warnings. As noted above, most of the data inputs for these forecasts derive from satellites. The latter data are especially important in geographic areas at risk from severe storms. Our study also shows that the industry has need of other types of satellite data. For example, some companies use NASA's MODIS data to estimate snow cover and Landsat data to assist in meeting environmental regulations on transmission line rights of way. All of these data contribute an economic benefit to the industry, which, in a competitive environment, will generally result in greater efficiencies and in lower electricity prices to customers.

Satellite information can also provide significant benefits in planning and operating electric production dependent on renewable sources of energy such as wind, sunlight, and water. At least seventeen (17) states have now mandated the use of renewable energy sources in generating electrical power; in the future, other states are likely to add similar regulatory requirements. Satellite-based remote sensing can aid in realizing the potential of exploiting renewable energy resources by helping in the optimal location of generating facilities as well as in the operational decisions of generating facilities and electric power grid management. The future growth and development of this increasingly important sector of energy generation would be significantly assisted by NASA satellite data which can provide a principal ingredient for this effort to assist in the siting and operations of these energy sources.

More accurately measuring the economic value of the contribution of satellites would help in guiding federal policy toward the electric utility industry. However, the use of weather and climate forecasts and other satellite data in this industry represents only part of the total benefit inherent in the environmental information gathered by spacecraft. Many other weather-dependent economic sectors, including water resources, agriculture, construction, recreation, and the general public would also profit from a better understanding of the benefits and mechanisms of both weather forecasting and the use of those forecasts. These economic benefits are most evident in the ability of better weather forecasts to reduce the risks and uncertainty in planning and performing a wide variety of economic and social functions.

Global Earth Observation System of Systems (GEOS)

In July 2003, the United States invited other countries to enter into discussions regarding the establishment of an Integrated Global Earth Observation System (IEOS) that would gather as much information as possible from current Earth observation systems operating in space, the atmosphere, and on Earth, with the goal of establishing comprehensive data and information systems to guide our management of planet Earth. That initial meeting was a resounding success and led to the current 10-year Implementation Plan agreed to by more than 30 countries in July of 2004.

The Implementation Plan, which consumed considerable effort in all countries party to the agreement, is only the beginning of many years of additional effort to bring the plan to fruition. NASA plays a very important role in this effort, supplying new, more useful satellite data sets and assisting with development of models and other tools to make the data sets truly useful.

This international system can provide significant additional benefits to the United States, as well as to the rest of the world, in many ways such as reducing hunger and providing better warnings of impending natural disasters. I note, for example, that one of the chief tasks of GEOSS will be to focus on methods and means to reduce the impact to life and property from natural disasters, such as earthquakes and Tsunamis. Satellite data and methodologies have an important place in this effort through their ability to gather real-time data on a worldwide basis which is one very key element of the modeling, forecasting, and warning system.

Having established its leadership in GEOSS, the United States must now follow through on its implementation. This will require sufficient funding for the U.S.

effort, the Integrated Earth Observation System (IEOS) both in continuing NASA's Earth science program at a robust level, and in supporting the involvement of other agencies in the endeavor. As noted in a recent report by the American Meteorological Society, "there will have to be a long-term robust research program designed to add value to the operation of IEOS."[4]

Such support should also include research on the expected benefits from such expenditures and sustained efforts to include the inputs of information users—the final stakeholders in the IEOS process. After all, there is only so much public money to go around, especially in an era of increasing budget deficits, and understanding the areas likely to return the greatest benefits will help NASA managers and Congress make better funding decisions among the many worthy research projects and proposals.

Bringing Benefits to Users

Despite the importance of maintaining a vigorous Earth science program at NASA, obtaining more accurate, more detailed scientific data from satellites does not automatically lead to economic benefits to users of the information. The many and complex steps between the development of forecasts and other decision support tools from satellites mean that expected benefits are not always fully realized by the end user. Hence, considerable effort must be expended to improve both the understanding of all parties involved in the process. This especially includes the communications between the research community and the ultimate users of the information.

Second, the transfer of Earth observations information from the producing agencies of the government to the end users must occur in a timely manner and in easily used formats. At present this is not always the case. With better appreciation of the roles and needs of the research, modeling, and end user communities, economic and social benefits of weather information can improve. We need a series of efforts to improve the flow of research results to information end users. I cite as an excellent example, H.R. 426, the *Remote Sensing Applications Act* sponsored by Representative Mark Udall, which would institute a series of competitively awarded pilot projects to encourage public applications of Earth observations data.

Yet, such efforts to incorporate beneficial Earth science results into the wider community will not be enough. In general, NASA and the agencies that use its data to improve their operations also need to focus on more effective technology transfer, communication, and coordination among them. After all, NASA is in the research and development (R&D) business, and the user agencies as well as the private sector mold NASA's data and other research results to specific users in the transition from research to operations. It is always easier and more accurate to quantify the end-use applications than the R&D. Yet, they are so inter-linked in a "but for" chain of events that benefits achieved by the end users would not and could not exist without NASA's research. NASA's Earth Science Applications Program is on the right track in centering its efforts on working with the user agencies to improve their processes. However, it will need continued support and encouragement from Congress and from within NASA itself.

Conclusions

In summary, NASA's Earth science program has provided sustained benefits to the United States. Nevertheless, in order to do more focused, cost-effective planning for the next steps in Earth science research, the United States needs a comprehensive, long-term effort to estimate both the measurable economic impacts and non-quantifiable social benefits of Earth science research and applications.

I see several ways in which this committee could be especially helpful in assuring that the public actually reaps the benefits of Earth science research:

1. Eliminate the steady decline in the proportion of NASA's budget devoted to Earth science. NASA's Earth science program produces real benefits to the American public and should be maintained at a level that maintains strong U.S. leadership in Earth science research.
2. Provide additional resources to support U.S. leadership in GEOSS.
3. Authorize NASA to direct greater attention to the quantification of the benefits of Earth science research and applications to America's industry and public sector, and the policy implications of those benefits.
4. Include an exploration of the issue of "transition from Earth science research to useful applications" in the Committee's next hearing related to Earth science and applications.

In the eyes of many, Earth science research is not nearly as "sexy" or as cutting-edge as exploration beyond Earth orbit. It certainly doesn't command the same sort of public attention as the astounding results from the Hubble telescope or the Cassini Mission to Saturn. Nevertheless, though it may not be as much in the public eye, Earth science research truly does involve exciting new technological developments and may be vastly more important in direct and near-term impacts to the economy and the public welfare than these other examples. Modern society has come to depend on the new knowledge and technologies that NASA's Earth science program provides. Just imagine what our lives would be like if our Earth science and meteorological satellites all suddenly failed. Tomorrow's weather would again become guesswork and electricity would start to cost us more. Local and regional environmental trends would be next to impossible to determine and monitor. Ships in the North and South Atlantic would be vastly more susceptible to iceberg collisions and other hazards. Resource exploration and resource management would be much more difficult to undertake. Even the security of our homeland would be lessened and our defense efforts hindered. Finally, we would be deprived of the benefit of seeing for ourselves the satellite weather maps on the evening news or over the Internet. In short, we would stand to lose the substantial benefits that we have already gained from Earth science research and application to the detriment of society. Continued aggressive support of these R&D and operational efforts is an essential component of the future of the economy and security of our nation.

Thank you Mr. Chairman, for this opportunity to present my views on these important topics. I welcome questions or comments.

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BIOGRAPHY FOR RAY A. WILLIAMSON

Ray A. Williamson is Research Professor of Space Policy and International Affairs in the Space Policy Institute, The George Washington University. He is Principal

Investigator for the NASA–NOAA funded study of the Socioeconomic Benefits of Earth Science Research, and was recently Co-Investigator of the U.S. Department of Transportation-funded Consortium: Disaster Assessment, Safety and Hazards for Transportation Lifelines. He is co-author of a recent major report on the U.S. remote sensing and geospatial market, and was Chair of the Space Policy and Law Department in the International Space University 2004 Summer Program.

From 1979 to 1995, he was a Senior Associate and Project Director in the Office of Technology Assessment of the U.S. Congress. While at OTA, Dr. Williamson was Project Director for more than a dozen major space policy reports on a variety of space subjects.

Dr. Williamson is a faculty member of the International Space University (ISU), Illkirch, France, teaching general space policy and Earth observations for the ISU Masters of Space Studies and Summer Session programs. He has lectured on space technology and policy in regional, national, and international forums.

Dr. Williamson received his B.A. in physics from the Johns Hopkins University and his Ph.D. in astronomy from the University of Maryland, and spent two years on the faculty of the University of Hawaii studying diffuse emission nebulae. He taught philosophy, literature, mathematics, physics and astronomy at St. John's College, Annapolis for ten years, the last five of which he also served as Assistant Dean of the College.

Dr. Williamson is a contributing editor to the journals *Space Policy,* and *Imaging Notes.* From 1998–2001 he was a member of the Aeronautics and Space Engineering Board of the National Academy of Engineering. He is also a Corresponding Member of the International Academy of Astronautics.

Published books include:

2001: *Commercial Observation Satellites: At the Leading Edge of Global Transparency,* ed., with John C. Baker and Kevin O'Connell (RAND and ASPRS).

2001: *Dual-Purpose Space Technologies: Opportunities and Challenges for U.S. Policy-making,* (Washington, DC: Space Policy Institute)

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DISCUSSION

THE IMPORTANCE OF EARTH SCIENCE AT NASA

Chairman BOEHLERT. Thank you, Dr. Williamson, for focusing on the very real and tangible benefits that the Earth science program brings to us on the planet Earth.

You know, these aren't the easiest of times in terms of budgetary consideration, and we are not surprised when distinguished scientists come before us and say, "At least give us as much, if not more." It is impossible to honor all of those requests, but I am somewhat concerned that NASA is being viewed, by some, as almost a single-mission agency, and it is much more than a single-mission agency. And I am proud to identify with the various missions of NASA, including the President's Vision for Space Exploration.

But Mr. Diaz, thank you very much for your testimony, and I noted, with particular interest, the comment that we are clearly emphasizing a continuing commitment to Earth science and NASA's commitment to study the Earth science. And you say that is clearly reflected in our national objectives, maybe in the objectives, but not as clearly reflected in the budget submission. And I see programs being canceled. I see the fate of the GPM mission, the Global Precipitation Mission, which the Academy says is extremely important and we should go forward.

And so, you could have fooled me, I guess I say in response to your assertion that this is a very high priority. It is important, but it is not as high a priority as some of us would like.

And I would like to ask the other witnesses across the board: can you give us a sort of insight as to your view of NASA's particular role in Earth science and why it is so important?

Dr. Moore.

Dr. MOORE. I think that you put it perfectly with the word "science," that many of the extraordinary benefits that Dr. Williamson mentioned, practical benefits, came from first the research, scientific basis. My best analogy—because the Earth sciences are somewhat different from the astrophysics, say Hubble, my best analogy is the medical sciences. I think the Earth sciences are in the same relationship. They have a responsibility for science, because they are scientists, as well as the applications of that science.

My concern is that the scientific part may be undermined. I certainly recognize that we have to look at this collaboration with NOAA. But it certainly cannot be a collaboration of centrally moving observational capabilities to NOAA and not, at the same time, bringing new observational capabilities into the agenda with rich scientific funding. That is what worries me is that there could be a decline at NASA, and maybe even an increase at NOAA, but the balance would not be right.

Chairman BOEHLERT. Thank you.

Dr. Killeen.

Dr. KILLEEN. NASA plays a crucial role in the fabric—the intellectual fabric of capacity and human capital in the Nation. I think the AAAS mentions that NASA provides 34 percent of the funding to our whole national Earth science capability, environmental sciences capability. So it is a dominant agency. But its role is—the focus, as Berrien points out, on the research, on the seed corn, on the new technologies, on the innovation that then can be extended and utilized more broadly to support society through operational capabilities.

And I think the history has shown that it does that extremely well. The doors have opened on plate tectonics, air pollution, weather, climate, many of the examples you say could be filled up with—there are numerous examples where we could point to NASA's innovation opening intellectual doors. I think we stand at a point in history where the work of the past decades has suggested that we need to take this life science analogy and look at the Earth as a system. We are capable of looking at the Earth as a system and actually investigating its metabolism, its function across a whole range of parameters and factors. NASA will support that. NASA is probably the only agency in the world that has the wherewithal, the track record, and the access to the human capital to make that happen. And that is going to be something that is so important for future generations, and it is going to drive economic benefits.

If you think about the U.S. economy, roughly $\frac{1}{3}$ of it has some sensitivity to environmental change: leisure, tourism, energy, transportation. And we are going to need decision support systems to support those enterprises that take into account the changes that occur locally, regionally, and globally as well.

Chairman BOEHLERT. Thank you.

Dr. Solomon.

Dr. SOLOMON. First of all, I agree with what Dr. Moore and Dr. Killeen have said.

To me, NASA's special role is the combination that they bring of scientific exploration and discovery and technological innovation. And I don't think they are matched anywhere in the federal system or even internationally. That gives them a special perspective, an opportunity to contribute to scientific issues.

And as previous speakers have said, the scientific issues driving Earth science are highly relevant to all of us who live on this planet. If we are trying to understand why earthquakes occur, why—where they do and when they do, from a purely scientific standpoint, that is a first-order question in Earth dynamics. But if you are living on a fault in California or Colorado or Oregon, it is more than an academic issue. The same thing can be said about other natural hazards where space can provide a perspective, and what is needed are new ideas, new technologies, new observation tools to open up the discoveries that will allow us to understand these systems. That is what NASA does best. And I see NASA playing a special role for continued investigation of the Earth for the foreseeable future.

Chairman BOEHLERT. Thank you.

Dr. McNutt.

Dr. MCNUTT. Yeah. NASA is simply the only civilian agency that has the required capacity, tradition, and track record to undertake the technology development to fuel tomorrow's discoveries. Imagine if we had a business community in the U.S. and we cut it off from the venture capital completely. And imagine what would happen to our business community. That is exactly what you would be doing to Earth sciences. NASA provides that venture capital.

Chairman BOEHLERT. I like your style. You put it in very practical terms. But I want to make sure that everyone understands this is not some esoteric discussion among scientists. This is something that has very real, very practical implications on our daily lives, as Dr. Williamson pointed out, in terms of billions of dollars in economic activity and saved lives and hundreds of millions of dollars in saved—Dr. Williamson?

Dr. WILLIAMSON. Oh, I think to echo some of my colleagues' points, the—a lot of the benefits that I have talked about in my testimony and other people this morning and at other times have discussed, started the understanding that you needed to pursue those practical benefits down the line really started at NASA. And you know, I know when I worked as a staff member for the Congress a few years ago, I used to get a little impatient with scientists, my fellow scientists, who would come to us at the Office of Technology Assessment or in one of these hearings and argue for more money for science for the sake of science.

But in fact, I don't see that happening. I see a very reasoned exposition in the National Research Council report that actually looks in detail at why one wants to support certain kind of critical missions. And the GPM is certainly one of those.

Chairman BOEHLERT. Thank you very much.

Here is the situation. We have a call of the House for a vote. We will have time for Mr. Gordon's questions, and then we will take a brief recess and hope we can get back in a timely manner. And I would urge all of my colleagues to return. This is a very important hearing.

Mr. Gordon.

Mr. GORDON. Thank you, Mr. Chairman.

EARTH SCIENCE CUTS

Mr. Diaz, I recognize that your job here today is to defend the cuts and cancellations that NASA has made to the Earth science budget, and you may feel like the victim of a drive-by shooting, but these are all very legitimate concerns and questions. And they really—they are predicated on the fact, as Mr.—or Dr. Killeen pointed out, that NASA has a great history and providing—and you have been a part of it, of research that is real-world to the country, and that we are afraid that this research and billions of dollars in foundation could be irrevocably damaged here in this window. So these are legitimate concerns.

With that said, I would like to better understand, if you could help me, NASA's rationale for making some of the cuts. For example, NASA's fiscal year 2006 funding request for the Combined Earth-Sun Science Program is some $645 million lower than the funding plan for fiscal year 2006 that was contained in NASA's fiscal year 2004 funding request. That is a 24-percent reduction in NASA's Earth-Sun Science fiscal year 2006 funding plan in just two years. Why did NASA decide to cut its planned funding request for the Earth-Sun Science Program so much, and where did the NASA-diverted funds go?

Or take another example. Just last year, then-Administrator O'Keefe told the American Meteorological Society that we hope to accelerate the flight of Glory Mission to as early as 2007 to provide earlier availability to this space-based pilometer. Yet we now find that fiscal year 2006 budget request that NASA is, in fact, canceling the Glory spacecraft and has no clear plan for flying Glory instruments any time soon. Was Administrator O'Keefe misinformed, or was the money intended for Glory diverted to some other purpose?

And finally, I mention NASA's decision to cut the out-year-funding plan for Earth science contained in last year's budget request by a significant amount. Why, given all the stresses on NASA's Earth science budget, did NASA decide to cut NASA's out-year funding plan for Earth science instead of taking the alternative course of slowing the pace of new exploration initiative? Mr. Diaz?

Mr. DIAZ. Well, there are a lot of questions there. And if we have the time, I would like to first start by saying I find myself in this unusual position of being refreshed by the observations of everyone in the panel who have talked about the wonderful success that NASA has achieved. And as you said, it does feel good to have been part of that.

And yet I also find myself in a situation where I can understand the concern, because of the change in strategy that is taking place.

The reason that I feel more confident is largely because I believe that when we come out of this transition, we will be much better positioned to do the work that we have been doing in the past than we would otherwise. What has been said is that we have made major investments over the past 15 to 20 years, and that is exactly correct. But a lot of that investment, I would hesitate to say how much of it, has gone into what I call infrastructure, platforms that hold instruments. The wonderful achievements that people are talking about here have to do with the achievements associated with the instruments that fly on these platforms. The platforms themselves are very similar to the ones that—if not identical, to the ones that NOAA flies for operational programs.

And so the strategy that we are on is one that would try to minimize the investment that needs to be made by the government overall in infrastructure to support these instruments. And many of the changes that——

Mr. GORDON. Well, is NOAA going to be given the funds to go along with these additional——

Mr. DIAZ. NOAA already flies these platforms, and——

Mr. GORDON. So there is no additional expense that will be incurred?

Mr. DIAZ. As I said in the past, I don't have the particulars with respect to the NOAA budget, and I cannot tell you whether or not——

Mr. GORDON. Well, don't you think—I mean, that is—you are saying you are going to the swimming pool, but you didn't check to see if there is any water in it.

Mr. DIAZ. Well, I—we know that they are building the platforms, and it is not clear to me how much money they are spending on them, but they are building the platforms.

Mr. GORDON. Well, one of the things that I have been very encouraged by your conversation is you want to have an openness——

Mr. DIAZ. Right.

Mr. GORDON.—and a dialogue. Well, don't you think part of this dialogue ought to be checking with NOAA and with the Administration? I mean, but even if what you are saying can be done and that there—and that basic science and applied science can be combined here, it still has to be paid for.

Mr. DIAZ. Yes.

Mr. GORDON. So I mean, I am not even sure that, again, it can be consistent. But even—but if your premise is correct, don't you think you need to check and see whether or not it is going to be funded and—as part of this dialogue you are having?

Mr. DIAZ. Well, I think what I—well, we have assurances and have gotten assurances that the development of the platforms has been funded and that there is space on them for us. But I just use that as a backdrop trying to get to answering your question.

There were—in the course of the past two fiscal years, your numbers are correct, and we have reduced overall in the Earth System Science as well as the Sun-Earth Connection combined, by that amount of money. If you look at what we did in Earth sciences alone, that is what was Earth science in 2004, because I can't compare—because they weren't combined in 2004, there was a reduction taken in 2005 and virtually no reduction in 2006.

I can answer the question about the details. I am not sure that you have the time at this point.

Chairman BOEHLERT. When we have—we do have to go, because we are down to four minutes.

Mr. DIAZ. Okay.

Chairman BOEHLERT. We will resume, at this point, when we come back. But I just would like to observe, you talked about the handoff——

Mr. DIAZ. Right.

Chairman BOEHLERT.—and I am enough of a track man to know it takes two hands for a handoff. And one hand is extending to hand off, but there has got to be a recipient with a plan and a program and the funding behind the program. And so—and we don't see that.

So we will take a brief recess and be back as soon as possible.

Mr. DIAZ. Thank you.

[Recess.]

Chairman BOEHLERT. We will resume, and before recognizing Mr. Calvert, before we were so rudely interrupted by the House demanding our presence there, we were having a very important discussion. And there is a minute left on Mr. Gordon's time, and then we will go to Mr. Calvert.

RELATIONSHIP BETWEEN NASA AND NOAA

Mr. GORDON. I guess quickly, Dr. Moore, would you like to respond to Mr. Diaz's comments?

Dr. MOORE. Yes. I think I know where you are going or what you are thinking there. This relationship between NASA and NOAA, is that what we are——

Mr. GORDON. And also following up on the Chairman's earlier comment. In layman's terms, what are the particular sciences that we could lose? I mean, are we going to have, in terms of weather, agriculture, you know, what are some of the real-world——

Dr. MOORE. Right.

Mr. GORDON.—potential losses?

Dr. MOORE. As I tried to say earlier, I think that the partnership, the long-standing partnership between NASA and NOAA is one of the most valued aspects of the United States government. It is almost unique in the world, and it is extraordinary. And I applaud anything to strengthen that.

However, I think we have to also recognize that they are, by mandate, very different agencies. NASA is a research and development agency. NOAA is an operational agency. NOAA has research capability, but it is far, far smaller than the significant, as Dr. Killeen pointed out, this very significant research capability of NASA. My analogy, to use the medical one again, would be if we somehow said we were going to move—essentially remove the NIH and rely on the hospitals to do the research, granted hospitals do research, we have research hospitals, but we certainly need the NIH. I think in the same vein that the Earth science program at NASA is central for NOAA's long-term viability that the—that all of the observational capability, such at NOAA, first came through NASA and that that train—or that theme should not stop. The areas of research we are just beginning to understand how the atmosphere is changing.

The point that Dr. McNutt made on climate variability, all of this has come about in the last 10 or 12 years, and we still are just beginning to understand it.

Chairman BOEHLERT. Thank you very much.

Mr. Calvert, the distinguished Chairman of the Subcommittee that has responsibility for the wonderful programs within NASA.

Mr. CALVERT. Well, thank you, Mr. Chairman, for the opportunity to make a couple of comments and to ask a question.

TRANSFERRING EARTH SCIENCE FROM NASA TO NOAA

I feel compelled to come to the defense of NOAA and the United States Geological Survey. I used to chair that Subcommittee before Mr. Ehlers and—for a number of years, and I found the people at NOAA and USGS to be top-rate, and some of the—and there is science taking place there. I think that some folks are saying that—if you would listen to some of the panelists, you wouldn't think that there is any other science taking place other than NASA.

And I would like to ask Mr. Diaz a question. Has the Administration ever said that they are going to get out of the Earth science business?

Mr. DIAZ. No, they have not.

Mr. CALVERT. No, that is not what I have heard you say. You are talking about a national policy on Earth science, which I think is an important thing. We a number of agencies—and I also serve on the Armed Services Committee. The United States Navy is doing a tremendous amount of research. We have the National Reconnaissance Office. It is—it puts up satellites. As a matter of fact, we have one coming up next month and another one the month after that. We have a number of agencies doing work, and I suspect those agencies are not talking to one another. I know they are not, because I looked at a map of underwater—of the obstacles that we deal with underwater. I suspect the Navy has done a lot of things that we, unfortunately, can't talk about or look at that are significantly more involved than what NOAA has done or NASA has done, for obvious reasons.

And so we need to have more interaction, so a national policy, I don't think, is a bad thing to pursue. You know, change is hard in this town. And I do agree with the Chairman that we should never make strategic decisions based on budget constraints. Strategy should always come first. That should always—whether it is on the aeronautics side and having a vision for aeronautics as we have on a vision for space, which I certainly support. We ought to have a vision for Earth science and how we deal with that in the future.

But Mr. Diaz, I want to give you the opportunity, because you are kind of outnumbered here today, to defend the Administration's position and how we can improve science and improve the interagency cooperation, which is not taking place today.

Mr. DIAZ. Well, as I said, I do find myself in this unusual position. Having worked with Berrien Moore for so many years, it is heartening to hear him say that—how much we value what NASA has done, and he didn't say anything in his last statement that I disagree with.

I will say that I think there has been an awful lot of change taking place and an awful lot of dialogue between the agencies that is documented in at the program level and is also documented in assignments that come from nationally-directed programs. But we do not have a single place to point to that talks to the strategy that NASA and NOAA are following to transition to this new environment. There is no intention that I have seen, nor do I see any evidence, of NASA abandoning Earth science. This is about transitioning to a different way of doing it.

Mr. CALVERT. As I see it, a better way of managing the resources, and to come out——

Mr. DIAZ. Absolutely.

Mr. CALVERT.—with a—hopefully, a better outcome. I agree that NASA should not be a single-purpose agency, but it should have priorities, and I think its number one priority is space exploration. And the technology to get the satellites in orbit at low-Earth orbit or whatever orbit we choose to put it in to make sure that we have the ability to get NOAA or any other agency that we need to deal with the ability to do the type of science that we are looking at.

And so I just wanted to come to the defense of NOAA and the United States Geological Survey and the job that they are doing, and I think they are competent folks over there. And I hope that as we go through this process, that we recognize the good work that they are doing and look at ways we can do a better way of interagency cooperation.

One last point. NASA lost a considerable amount of business in the last number of years, I have only been Chairman of this committee for a little while, to the Department of Defense. For whatever reason, the Department of Defense took it upon themselves to do research in aeronautics and space design outside of the NASA preview. That was unfortunate, Mr. Chairman. And for whatever reason, we need to help rebuild that relationship. And I think we have a new Administrator that can look at the entire scope of what NASA has done in the past, where have they gone and maybe lost their sight of where they need to go. I am an old business guy. I believe in business plans. And get them back on track. And I don't think the Administration is trying to hurt the Earth science industry. I think they are trying to help it.

So with that, thank you for letting me have the time.

Chairman BOEHLERT. Thank you, Mr. Calvert.

And just let me say how much we value your continued contributions to this committee and its deliberations. I couldn't agree more with you that the national policy is very good in theory, and I want to have that national policy. And Dr. Moore, I hope in the study you might maybe give us a road map on how we accomplish this. I mean, a national policy makes sense for a nation. But maybe it is NASA doing the basic research and maybe the applied research is done elsewhere. That is part of a coherent, national policy. But while I am comforted by your continued commitment to Earth science, the fact of the matter is when you said to Dr. Moore how much you welcome his comments on how valued Earth science is, I welcome those comments, too. And I know how valuable it is.

That is why I hate to see the Earth science budget significantly reduced because of the great value in very real terms to the Nation and its important impact on the Nation in practical terms, not just theoretical discussions among scientists.

With that, let me recognize the distinguished gentleman, Mr. Green.

Mr. GREEN. Thank you, Mr. Chairman and Mr. Ranking Member. I would like to thank you for the panel that we have assembled, the witnesses. Outstanding, each. And I think that you have given a neophyte a wealth of information, and I greatly appreciate what you have shared with us.

GLORY

Mr. Chairman, if I may, I would like to refer to a table from the NAS report, Table 3.1, styled canceled, descoped, or delayed Earth observation missions. And I would like to just mention a few things from this table, and I shall do so quickly.

Missions, global perception—pardon me, precipitation, measurement, this one is unclear, atmospheric surroundings—excuse me, soundings from geostationary orbit canceled. Ocean vector winds, canceled. LandSat data continuity, reformulated. And then Glory is listed as unclear. I would like to focus on Glory, because there is much talk about global warming. And there seems to be the notion that it really does not exist. I was hoping that Glory would give us additional feedback such that we could make some intelligent comments about this global warming debate that has been raging in our country. My understanding is that Glory was to be a stand-alone mission in 2008. Thereafter, there was talk about a piggyback mission, that is with another mission on-board, with another mission. And I see now that there is an NAS Committee interim report, which addresses the possibility of it being suitable or capable of being timely placed with another satellite.

So my question is, after much consternation, are we going to have a Glory mission, and if so, what type of timeline should we expect?

Mr. DIAZ. Well, I assume that is for me.

Mr. GREEN. Yes, sir.

Mr. DIAZ. Okay.

Mr. GREEN. Thank you, Mr. Diaz.

Mr. DIAZ. Okay. Yes, we do have plans in place and are developing the elements for a Glory mission. The current situation is that the budget that we have supports the development of the instruments for a Glory mission with the expectation that we were going to fly those on a—one of the NPOESS satellites. In the current situation, with the review ongoing of the NPOESS satellites, we decided to continue the development of a spacecraft, which is a spacecraft that was partially built and is being built by Orbital Sciences here in the Washington area. We are continuing that with the expectation that over the course of the next several months we will make a decision as to whether or not to fly Glory as a stand-alone mission or to fly the instruments on a bus. If we fly it on a—as a stand-alone mission, we will need to complete the development of that spacecraft and then decide how to get it launched. But want to assure you that we intend to fly the Glory mission and are continuing to develop the instrument. There is some uncertainty about how we would ultimately get the instruments into space.

Mr. GREEN. And a quick follow-up, if I may, Mr. Chairman.

How have we budgeted the mission, because if we are not sure that it will be stand-alone or piggyback, how are we managing to budget that?

Mr. DIAZ. In terms of the runout, we have budgeted it, excuse me, as if it was going to fly on one of the NPOESS satellites. In terms of this fiscal year, the budget that we have available will support the continuation of the bus development. And what we will have to do, if we decide to fly it as a stand-alone, is to change the budget in the out-years during the fiscal year 2007 budget process.

Mr. GREEN. Thank you, Mr. Chairman.

I yield back the remainder of my time.

Chairman BOEHLERT. Thank you very much.

And I just want to make sure you appreciate the fact that this committee doesn't think that global climate change, global warming is a figment of somebody's wild imagination. I might point out, neither does the President. He recognizes it as a serious issue, as he should. But whether you are for or against on that argument, the fact of the matter is people on both sides recognize the importance of what Mr. Diaz and his people are doing and we are hearing from these distinguished scientists confirming the importance of that.

Thank you very much.

The Chair is pleased to recognize Dr. Schwarz.

Mr. SCHWARZ. Thank you, Mr. Chairman.

THE EFFECTS OF EARTH SCIENCE CUTS ON UNIVERSITIES

To my fellow University of Michigan Wolverine, Dr. Killeen, many universities have programs in Earth science and topics and subjects that are pertinent to Earth science that are pretty well developed, University of Michigan, of course, being one of them, but there are so many others. If NASA continues to decrease the size of what it does in Earth science and in the Earth sciences, how is that going to affect programs in places like Madison or Cambridge or Berkeley or Durham, New Hampshire or other places? Is this a deleterious effect, or does life go on without NASA going heavily into Earth science and aggressively into Earth science.

Dr. KILLEEN. I think that there is a potential for a deleterious effect on the development of human capital in universities, such as University of Michigan, and other places. And I note that NASA has 34 percent of the national investment in Earth sciences. Most of that is—the predominant part of that is in satellites, platforms, database management systems. But there is also a very significant fraction in the research and analysis programs that extend into the research laboratories in the universities and from graduate students, undergraduate research topics, curriculum development efforts as well. And those are very vitally important programs, I think, across the Nation. So the research and analysis. And I think at the last reckoning that NASA is, like, ranked number third in terms of federal agencies in supporting that element of the program.

These are important for our students as they come forward. I used to teach at the undergraduate level non-science majors, Earth system sciences, and I can tell you from firsthand experience that these young people coming forward in the universities are very interested in how the Earth functions, what is going on, and how they can play a role. We used to talk about the need for a pre-life course sequence as well as a pre-med. course sequence in these major research universities. And the content of those curricular elements are similar to the slides that we have been showing today: sea surface, oceans, atmospheres, tectonic plates. NASA has provided really exciting content that is enrapturing our youth and building this human capital, and it is taking place across the country in research university campuses, certainly.

Mr. SCHWARZ. Can I deduce from that that there would be fewer—and Dr. Moore, please jump in, if you feel like you would like to, there would be fewer graduate students, post-doctoral scholars, research scientists on campuses were NASA to back off in their Earth science pursuits?

Dr. KILLEEN. Well, I will defer to Dr. Moore, but certainly if the funding goes down, in terms of research grants to university campuses, and NASA is a substantial contributor to this arena, then there would be fewer opportunities for graduate students to come forward. And those are the very individuals that we expect to design and implement the new technologies that will be transferred to NOAA operationally 10, 15, 20 years hence. So I think there is a pipeline of talent issue here.

Dr. MOORE. Well, we have already begun to sense the pressure on the research and analysis budget and how that pressure translates to the availability of graduate fellowships. And even though the fellowships say budgetarily are extremely small, under pressure, this begins to be felt, and we have already experienced it.

Mr. SCHWARZ. Thank you, sir.

And thank you, Mr. Chairman. I would yield back.

Chairman BOEHLERT. Thank you very much, Doctor.

The Chair recognizes Mr. Udall, who had a wonderful opening statement, and is going to spare us the reading of it. It will be inserted in the record with all of the other wonderful opening statements.

But now we will go with you for your wonderful questions.

Mr. UDALL. You can all see why it is such a pleasure and how wonderful it is to serve with Chairman Boehlert.

I did want to, in particular, welcome Dr. Killeen, and remind my good friend from the State of Michigan that Dr. Killeen now lives in my hometown of Boulder, Colorado, and I don't think he has gone to the dark side and supports the Colorado University teams, but——

Mr. SCHWARZ. I thank the gentleman for yielding.

Were he still in Michigan, I believe he lived in Dexter, and he would be a constituent of mine.

Dr. KILLEEN. No need to fight over me.

LANDSAT

Mr. UDALL. I want to direct my questions at Mr. Diaz on the LandSat situation, but I did want to acknowledge Dr. McNutt, in particular, on the second page of your statement, where you talk about some of the long-term lessons you have put into place. And

I think the Committee and the community would be well-advised to take a look at what you have discovered. So thank you. And I think it—there is an application across the board.

Mr. Diaz, I mentioned LandSat, and as you know, the current LandSat 7 is now past its design life and operating in a degraded condition. How much longer do you—your engineers estimate that LandSat VII will remain operational?

Mr. DIAZ. If you don't mind, I have Dr. Asrar here with me who has been intimately involved in that, and I would ask him to come to the table and answer that specific question, if you don't mind.

Mr. UDALL. If you could do it with dispatch, it would be appreciated.

Mr. DIAZ. Yeah. He is right here.

Mr. UDALL. We would like to hear from him.

Dr. ASRAR. Thank you very much. My name is Ghassem Asrar, the Deputy Associate Administrator in the Science Mission Directorate.

We have been working with our partners, NOAA and USGS, to do a complete assessment of the life expectancy, the reliability of the system. The current projection is that probably maybe two or three more years, although those are estimates. The same estimates that were used for LandSat 5, and we had projected LandSat 5 will not last longer than, probably eight or nine years. This is—I believe it is celebrating its 15th birthday. So these are engineering estimates. Probably, maybe two to three more years. And then in parallel, we are looking at other sources of data to mitigate any risks associated with the discontinuity, should it come to pass. And so we are preparing for the worst and hoping for the best, as we will work our way toward the transitioning the LandSat capability into the national operational infrastructure.

Mr. UDALL. Thank you for enlightening us in that particular point.

I noticed concern about a gap that may be produced that you are speaking to, but I want to ask Dr. Williamson, what user groups would be most affected if there is a gap in the flow of this data.

Dr. WILLIAMSON. Well, there is a wide variety of user groups throughout the world that use LandSat data for environmental monitoring. As you know, the swath width and the resolution size of each pixel in the image is much broader than it is for, say, the commercial high-resolution satellites. And that has an advantage, if you are doing exploration of the coasts and understanding large-scale issues that are taking place along the coasts or inland. In your State of Colorado, for example, LandSat imagery was very important in the fires that occurred, what, now three years ago, I believe——

Mr. UDALL. Yes.

Dr. WILLIAMSON.—just south of you. And it—those images really helped to understand the scope of the fire and the way it was progressing over a considerable amount of time. So you find a tremendous usage of those data throughout the world in similar kinds of projects. So losing LandSat would be a serious issue in part because it is a unique instrument. There aren't other instruments exactly like it. So it means that on the operational side, it becomes very difficult to take the data that you have been used to using from LandSat and then substitute other data and get the equivalent results. Other examples I could site would be down in Brazil, for example, watching the—tracking the deforestation in Brazil. The same thing in Russia and other parts of the world. And as has been already said, the environmental—major environmental changes that take place elsewhere in the world affect us as well. And we need to understand those better.

Mr. UDALL. Yeah. Well, the old saying, "We are all downwind from everybody else in the world."

If the Chairman might indulge me just for another question directed back at NASA and Mr. Diaz.

Given what we have heard and I think what we understand about LandSat, what are you doing to address this potential data gap, and how much money are going to budget to obtain LandSat-like data from alternative sources?

Mr. DIAZ. Again, Dr. Asrar is involved in actually working that, so let me ask him to come back and talk about that.

Mr. UDALL. If I could, too, Mr. Chairman, I would like to submit some additional questions to NASA——

Chairman BOEHLERT. Sure. That would be——

Mr. UDALL.—along this line of questioning, but if we have a minute to hear——

Chairman BOEHLERT. Sure. As all Members of the Committee are going to be afforded that opportunity, and we would appreciate, obviously, timely responses.

Doctor?

Dr. ASRAR. Mr. Chairman, and again, thank you for the opportunity.

Given the sort of broad reach of LandSat, its utility throughout the government, we at NASA haven't been doing this unilaterally. We have been working with all of our sister agencies and the Offices of the Office of Science and Technology Policy to develop a national plan for dealing with the potential data gap. And all of the users are at the table: U.S. Department of Agriculture, U.S. Geological Survey, Department of Interior, and NOAA. So the plan that we are developing, given that it is a work in progress, we thought of scoping what is required and what are the sources of data and which part of the data could be obtained through international cooperations. For example, the 33-year record of LandSat data is something that everybody is benefiting from. But there are other nations, like India and, as of late, China, who have developed comparable capabilities. They have these type of observations. On the EOS spacecraft, there is an instrument called ASTER that has comparable LandSat capability with much reduced swath, about 60 kilometers. We have another technology demonstration satellite on orbit called Earth Observer I that has comparable LandSat capabilities. So we are going to bring all of the data sources together, regardless of whether the government-owned or internationals to fulfill the LandSat data continuity needs, and depending on what are the best solutions, identify the resources within the government to fulfill that. The major commitment is to maintain the continuity and whatever resources are required to make it happen, I am pretty sure our government will be up to supporting that.

Mr. UDALL. Thank you, Doctor. I think we are all concerned on this panel that data conversion, that data integration is still a very complicated and challenging one, and I think Dr. Williamson put it very, very well.

Chairman BOEHLERT. Thank you very much.

The gentleman's time has expired.

Mr. Rohrabacher.

Mr. ROHRABACHER. Well, I don't want to destroy the wonderful spirit that we have at work here, but I do have some—a couple pointed questions, maybe. And Mr. Chairman, it might be nice to have at least one person on the panel who can actually stimulate the discussion by having a different point of view. And just my suggestion in the future.

Chairman BOEHLERT. We always rely on you for that.

CLIMATE CHANGE RESEARCH

Mr. ROHRABACHER. All right. I just can't tell you how, you know, just enlightening it is to understand that we are still considering another global warming mission. You know. Glory. I mean, just—I mean, how many billions of dollars do we have to spend on this? I mean, is it actually going to change global warming to have yet another satellite up there? My calculations since I have been here, that we have spent tens of billions of dollars trying to prove global warming, and every budget that we pass has this. And let me note something that happened, Mr. Chairman, when I first—not when I first came here, but sort of a few years into my tenure on this committee. A very high ranking official from NOAA came to see me to tip me off that El Niño was going to happen in six months and it would hit California. You know, we would hit it in about six months and the effect that it would have. And let me note he was exactly right. And that was—it really impressed me. And I said, "Gee, these guys really are focusing on some things that are useful." And being a surfer and everything like that, I really wanted to know the water was going to be warmer and the—more fish and there might be some forest fires because of the rain coming down, et cetera.

Anyway, the same fellow, by the way, in a hushed voice, leaned over to me and said, "Just to let you know, but don't tell anybody that I told you, but all of these calculations about global warming that they have made so far, they haven't taken into consideration the cloud cover on the days that the temperatures were taken. You think that might have something to do with whether or not they have a valid calculation?" And then—he was afraid to say that in public, but he sort of whispered in my ear. I just—you know, it just amazes me when you hear that so much what I would have to say is just fear, expressions of fear when the President starts talking about making just a restructuring of how we house and where we put research in the government.

Let me ask Dr. McNutt. I mean, you stated—I mean, this goes—this is something that I just would like to know how you justify this that somewhere from its root of the technological program that feeds innovation, the program would eventually die and wither—or wither and die. Aren't there just research programs that don't have to also have people who put machines together? And what makes you think that all research is going to wither and die if not tied directly to the technology that implements the research?

Dr. MCNUTT. What I meant by that is that if we—all we need to do is take the same sensors we already have and continue to fly them in space with no changes, no upgrading, then we probably could hand those off to another agency and put it just in maintenance mode. But I don't think anyone on this panel would support the idea that there won't be newer and better measurements that really need to be made to answer some of those questions. For example, you bring up the issue of cloud cover. Cloud cover has to do with aerosols. Aerosols are one of the most, right now, unknown parts of the climate formula. And putting new sensors in space would allow us to take some of those hushed questions that you are hearing behind closed doors and actually answer them so that we can make predictions for climate change.

Mr. ROHRABACHER. I guess all of those clouds, you know, in the past that people talked about before we had aerosol cans were just not really relevant to whether or not the Earth has changed its weather patterns over these last——

Dr. MCNUTT. Well, we are talking about aerosols not in aerosol cans, so to speak.

Mr. ROHRABACHER. Okay. Let me note that other testimony that I have heard here indicates that a lot of our investment that we—that even NASA already has in space, you know, our Earth Observing System, et cetera, that we have enormous unanalyzed data. Isn't this a travesty that here we are talking about how important it is to keep NASA in the loop, but here it has organized itself in a way that the product of what we are getting out of the investment, a huge amount of this data remains unanalyzed? Why—wouldn't we think that perhaps it might be better to give some other agency that is actually more oriented towards analysis and research some authority here rather than just keep giving it to the engineers that run NASA? Go right ahead. I mean——

Dr. MOORE. I would like to comment on that.

I think that there was a time when your statement was true. But I don't think that is the current situation. And I believe that it is not the current situation because of actions of NASA and also of the technological infrastructure of the United States and the planet. Today, undergraduates and high school students and graduate students, and even aging professors, look at NASA data every day on our desktop. It is remarkably easy to analyze these fire hoses of data, which 10 or 20 years ago, with punch cards, it was a very tough thing to do. So in a sense, modern society has caught up with Earth observation. And I do think you were correct in your assessment, but I don't believe it is where we are today.

Mr. ROHRABACHER. But does that still mean NASA has to continue to be the vehicle? I mean, I just—it——

Dr. MOORE. I think the issue here is that NASA is the primary R&D Earth observing organization. And as such——

RESEARCH PRIORITIES

Mr. ROHRABACHER. But the question is whether it should be or not. I mean, when we are talking about—NASA has its missions, you know, and here we have—it has evolved into what it is today.

And when—I don't imagine there is anyone on the panel that would disagree with a hypothesis that there is some research that the government pays for that is less deserving than other research. I mean, I imagine there are—even among a panel that is so committed to assign money for research, there is some research that would be better—the money might be used elsewhere. Well, when you restructure—and like the President is talking about, that is when you get rid of things that aren't worthy of the investment. That is where you make your choices as to what should have priority. And if you never restructure, it is just going to continue like it is, which is yet another global warming project, yet another global warming project rather than having a—or whatever the projects are, rather than trying to find out what things are more valuable with the use of government money. When I was—I am sorry I am going on here, but let me just note this that when I first—when we first got the majority and I was the Chairman of the Subcommittee on Environment and Research—and Energy Research, I looked over all of the different projects that were being funded, and I said, "How are we going to cut the budget, and how are we going to make sure the money is being best spent?" And I just looked down and said, "Which one of these projects is spending the most money and having the least results?" And it happened—I know everybody is going to get mad, fusion energy happened to come up, and of course, the academic community has never forgiven me for that. But the fact is, they hadn't come up with the results that other people were coming up with. And shouldn't we have a restructuring, in some way, that lets people use our science money in the most—and channel it towards the—actually the most sufficient rather than keeping on—always keeping on the project. Once it is—you know, once it is funded, it has eternal life. And I will leave that question with the panel. But——

Mr. SCHWARZ. [Presiding] The gentleman's time has expired.

The gentleman from North Carolina——

Mr. ROHRABACHER. If the Chair would indulge Dr. Killeen, just—he had something he wanted to say about that.

Mr. SCHWARZ. University of Michigan, anything. Keep it brief.

Dr. KILLEEN. Thank you. Thank you very much for those challenging comments.

I think, on the panel, we are talking about an end-to-end system of research—education, research innovation, transition to operations, support for the societal needs. They are quite practical, in fact. The element that we are emphasizing, because we were asked to, was the NASA element, which has been the R&D, the technology development, the invention of new instrument types, et cetera, as opposed to the deployment of operational systems. So that said, I think if we were—and we could all defend NOAA. In fact, my institution works closely with NOAA on next-generation weather forecasting and all sorts of things, and they are great people and do a wonderful job.

But if you think about the NASA's past contribution, which we have tried to highlight, in terms of technological innovation that has meaning, for prediction of El Niño, for prediction of the five-day weather forecast, for the prediction of what is going to happen in the next two hours in an airport when you are landing, for prediction of next season's thermal structure in the Northeast where the natural gas needs to deploy natural gas on a delivery, those are all things that society needs for which we need a knowledge base. And I think what might be at risk if NASA pulls back from its R&D mission in the Earth sciences, is developing that knowledge base that will support those kind of systems and tools into the future. And I could go on on this, but I won't.

Mr. SCHWARZ. The gentleman from North Carolina, Mr. Miller.

Mr. MILLER. Thank you, Mr. Chairman.

TRMM

Just following up on that, there have been several members of the panel, and of this committee, who have pointed to Earth observation as not something that simply satisfies a curiosity of academics or as, perhaps, and employment program for academics, but it has a definite application. And certainly in weather forecasting, it is useful to look at the comparison. This last—of where we are now and where we have been. This last year, we had an unusually active hurricane season. I think most of us who live on the East Coast watch with fascination the storms form on the west coast of Africa and march across, westward across the Atlantic, and make landfall here. We had at least two storms that were category four, which is an unusually powerful hurricane. Hurricane Charlie hit—made landfall in Florida. It was a category four. It resulted in 31 deaths, which is, of course, tragic. Hurricane Ivan also struck as a weak category four and resulted in 49 deaths, including 10 in North Carolina, largely as the result of flooding from heavy rains. And of course, that was tragic, too.

But the comparison of the kind of damage that came earlier in our history when we were much less populated but did not see it coming is dramatic. In, I am sorry, 1893, a storm of unknown intensity made landfall in Louisiana. The estimate is that there were 2,000 deaths from that storm. That same year, again, a storm of unknown intensity, made landfall in South Carolina and Georgia. The estimate of the loss of life is at 21,000. And of course, in 1900, the—what we now estimate to be a category four storm, hit Galveston without warning and resulted in eight to 12,000 deaths. And in 1928, a storm struck with very, very little warning in Florida and resulted in 1,800 deaths. That is a striking contrast, the level of loss of life that we suffered when we did not see it coming and could not prepare versus what we see coming—versus where we are now versus where we were then in our ability to prepare and how much difference it makes. And I certainly do hope that we grown in our ability to foresee other natural disasters and to forecast them to predict their—predict and prepare.

Mr. Diaz, I had a couple of questions about what NASA has decided, in at least one case, and more importantly, I think, how you decide. Last year, Japan announced that it was withdrawing from the partnership for the Tropical Rainfall Monitoring Mission, TRMM, and NASA initially announced that it would discontinue TRMM, even during that hurricane season. And the evidence, I think, or the belief of scientists is that the information from TRMM has aided in the forecasting of hurricanes, their intensity, and their path and I think largely because of the intervention of Members of

Congress. Mr. Boehlert wrote a letter, Chairman Boehlert wrote a letter. Mr. Lampson from Texas, who I think was then Chair of the—or rather Ranking Member of the Subcommittee on Space and Aeronautics wrote a letter to object and ask at least that TRMM continue in operation through the end of that hurricane season. Dr.—or rather Admiral Lautenbacher, is that the correct name, who is the Undersecretary of Commerce for Oceans and Atmosphere, which I think has jurisdiction over NOAA, wrote to Mr. O'Keefe and asked and said given our growing dependence on these NASA satellite instruments, I would appreciate an opportunity to work with you to develop a more formal mechanism for dialogue with NASA as—well in advance of any termination date for research data streams.

Mr. Diaz, you said that there is an awful lot of dialogue, I think was your phrase earlier, with the other agencies that depend upon NASA. Is there now—actually, Admiral Lautenbacher asked for a joint working group. And it is apparent that he thought that NOAA had been left in the lurch, simply being told that NASA was discontinuing the TRMM project.

What are current plans for TRMM, one? And then second, are you doing anything to develop that formal mechanism for dialogue so that the other agencies that depend upon NASA do not simply find out from reading the newspapers that NASA is discontinuing programs that they depend upon?

Mr. DIAZ. Thank you for that question.

And let me start by saying what the current status is of TRMM. Just—TRMM is currently being operated, as it always has been, and it will continue to be operated until such time as either one of two situations occur: either it becomes clear that it will exceed the hazard criteria associated with uncontrolled reentry that NASA policy requires for us to take action at, or until it becomes clear that it is no longer valuable as a resource or is less valuable than is worth continuing.

Now I will say that in the case of the former, we have some standards, and we have continued to look at the condition of the satellite and its ability to do a controlled reentry and have always had that capability.

In the case of the latter, that is the value associated with it, there was no formal process in place that had us interacting with NOAA or, for that matter, the rest of the community.

In the case of TRMM, there was a joint working group put together under the auspices of OSTP, and we came to the conclusion that TRMM ought to be continued as long as there was no hazard associated with it. And so we are in the process of continuing to monitor when that action would have to be taken, the de-orbit action.

But in the case of this value issue, we have put in place what is called a senior review process, which is much the same as the review process that we have in space science that will periodically, typically every several years, look at the continued—or look at the fleet of missions that are available to continue and prioritize them with respect to continuing them from the standpoint of scientific value. And in fact, as we sit here, the first of those senior reviews for the Earth science satellites is currently ongoing.

In terms of what the expectation is with respect to TRMM, we think within the next several months we will have to make a decision about deorbiting the TRMM mission. And if you don't mind, I would ask Dr. Asrar, who has more details, if you need anymore details, to go beyond that.

Mr. SCHWARZ. Thank you.

The gentleman from Michigan, Dr. Ehlers.

Mr. EHLERS. Thank you, Mr. Chairman.

I just want to mention briefly that before my colleague from California, Mr. Rohrabacher left, I entered his rhetorical question about how many more missions we would need on global warming, and I said, "We will probably keep doing them until you believe it is true." And I told him he had the power to stop the missions.

TRANSFERRING EARTH SCIENCE FROM NASA TO NOAA

Having said that, Earth science is a very important part of NASA, and I have to say, even though I am a scientist, when this was first discussed, I thought, "That is kind of a waste of money. Why should we waste all of that space hardware on Earth observation?" But I was dead wrong, because there is so much you can do from space in terms of Earth observations. And we often tend to neglect, as I did in my initial response, neglect our own planet. A good example of that is we had several thousand people now climb Mt. Everest. We had 100 or more—several hundred astronauts go into space, and we have only had two people exploring the depths of the ocean really at very significant depths. We tend to neglect our own planet. And I, during the Easter recess, gave lectures at two major universities on different parts of the country, but these are both on the top of American universities. And in both cases, the Earth scientists sought me out and said, "We are very concerned about what is going to happen with Earth science if NASA pulls the plug."

Well, I understand you are not quite pulling the plug, but you are saying, "We will just move it over to NOAA." NOAA does not have the capability at this point. You can't simply expect that if new sensors are developed we can just plop them on one of the weather satellites. There is compatibly issues, scheduling issues. I think it is—in view of NASA's excellent record on Earth observation, they have to continue to be involved, and not just say, "Okay, we will help design the sensors. We will put them up into space, but it is going to be your satellites. You have to manage that somehow." I am really concerned, too. It sounds as if NASA—NOAA has not been heavily involved in any way in the planning of this. If I am mistaken on that, I would like to know. But it sounds to me like the real problem is that NASA is low on money because you have been given big new missions, and you don't—weren't given the money to do it, so you are cutting and scraping as much as you can to get rid of what you regard as non-essential to the new missions. And I believe it is very important for you to continue to be heavily involved in Earth science.

And so I just think it is essential for us to keep a robust Earth Observation System going and both at NOAA and at NASA. They are complementary. And if we are going to transfer over to NOAA, what you suggested could go over to them, we are going to have to transfer some money from NASA to NOAA to do it, because we are not going to find any new money these days. Since they are both in the same Appropriation Subcommittee, I suspect it would be quite easy to make that transfer.

So if you are trying to save money, you may not end up saving money by doing this. I would be happy to listen to any responses from anyone on the panel.

Mr. DIAZ. Well, I would like to make sure that we don't leave the impression that—number one, that this is being done unilaterally. We are in conversation with NOAA very frequently, and we do have agreements in place for many of the elements individually. What we don't have in place is an overall strategy that is articulated that does what I have mentioned. And so I do think that if NOAA were sitting here today, they would recognize the fact that the things that we are talking about transferring or the things that we are talking about doing jointly, and I would rather think of it as things that we are talking about doing jointly as opposed to sending them things that we ought to be doing——

Mr. EHLERS. I hope you would, but I would also point out something else you don't have, and that is the approval of the Congress. Please remember that.

Mr. DIAZ. Okay.

Mr. EHLERS. You may proceed.

Mr. DIAZ. And the—in any event, I just wanted to make sure that we did register that NOAA is involved in these conversations and I think would acknowledge that, if they were here.

Mr. EHLERS. I appreciate that.

Anyone else wish to comment then?

Dr. Killeen? Anything from Michigan.

Dr. KILLEEN. Repeating theme.

I would like to comment on that. The central point of my testimony, for example, today is that a fundamental restructuring of the national program, which is what we are talking about here, should be done very carefully, deliberatively, with appropriate assessment of the effective contributions of the component parts. I do believe that the NRC decadal survey that is being commissioned by NASA and NOAA is a critically important part of that. It will take time to fully come to grips with it. We are not looking at the final report here, and I am not part of that panel. I am on the outside. But that assessment, I think, is essential to be so that all of the "I"s are dotted and all of the "T"s are crossed and so there is confidence in the communities that are invested in this and in the Nation that we will be able to proceed forward with this big enterprise.

Mr. EHLERS. Anyone else?

Yes, Dr. Williamson.

Dr. WILLIAMSON. I think nobody on this panel would disagree with the importance of occasionally restructuring how we think about our research and applications effort in Earth science, but I do think that we differ in detail on some of these matters probably, but in general, I feel that dropping or delaying longer missions like GPM and so forth, which are very important, not only to research, but to helpful and beneficial applications is probably not the way to go.

Mr. EHLERS. All right. I thank all of you, and I want to reassure you, Mr. Diaz, this—my questions and statements probably sounded antagonistic. They were not intended to be that so much as a warning. This is something—we regard this as a very major change, and it is going to take a good deal of work, hard work and coordination between yourself and NOAA, if it is to take place, and also the concurrence, and I would also say, involvement of both the research community and the Congress.

I—as a research scientist, I know how complicated research science is and how essential it is to plan well. And it can't be something that is just done because you want to get out from under the financial burden. I hope it is—the goal on your part, as well as NOAA's is to improve the science that is done. And if you can do that and improve efficiency at the same time, we will certainly be open to looking at that.

Thank you very much.

Mr. DIAZ. Well, thank you, Mr. Ehlers.

Mr. SCHWARZ. The gentleman's time has expired.

Mr. Costa from California.

Mr. COSTA. Thank you very much, Mr. Chairman.

USE OF EARTH SCIENCE PROGRAMS TO MANAGE THE WATER SUPPLY

I, too, share a similar feeling that the gentleman from Michigan expressed that I think many of the Members of this committee feel in terms of the prioritization for the Earth sciences program within NASA's budget.

I have been informed that Dr. Williamson and perhaps Dr. Killeen might be best to address a question that I have. For many years, I have been involved on the application of addressing California's current and long-term water needs. We have a saying in California that water is the lifeblood of our state and if you want to understand how California has developed economically and socially, you can trace it to one resource issue, and that is how we have managed our water resources.

But I think it is applicable, frankly, as it relates to the world. I think one of the sweeping issues we have today is the availability of water to sustain our population throughout the world and not only for communities for water quality, but also to provide for our crops, which obviously provides the sustenance.

I am concerned, Dr. Williamson, about the applicability, as we look at our water management tools in our water toolbox, about the availability of the use of the Earth science program and specifically the satellite technology as we try to address, not just in California's case, but throughout the country, availability of water as we try to forecast for crop productions and crop—annual crop yields as we try to attempt to ensure that we are doing our best to manage our water resources.

Would you care to comment?

Dr. WILLIAMSON. Yes, I will. Thank you.

You know, a famous poet once wrote that there is water, water everywhere, but not a drop to drink. And it usually is thought in that case, specific case, it applied to the ocean. But we are beginning to face that in critical areas around the world and certainly through the United—throughout the United States. And in your State of California, you have faced, over the years, a lot of concerns about that issue. And I appreciate that.

One of the tremendous advantages of satellite technology, and supported by adequate research, is the ability for satellites to see areas together in a so-called synoptic view, all together at one time. And that ability to gauge water resources by observing the quality of water in large freshwater areas and observing the sources of water in—especially in the State of California. A lot of your water is supplied by the snow in the wintertime in the northern parts of California and the states somewhat east of you. And in fact, we can begin to understand how much water is available by looking at snow cover and snow depth and so forth, and satellite imagery, satellite measurements of all kinds are very useful in that endeavor.

So there are a number of different applications that are possible, but we need better science to support those observations, and I know that NASA has a program to look at those kinds of things and that certainly needs to be continued. GPM is a good example of a system that would assist in that effort.

Mr. COSTA. Dr. Killeen.

Dr. KILLEEN. May I comment, too?

Mr. COSTA. Sure.

Dr. KILLEEN. The problem with a regional access to water is a wonderful case study of this need for Earth system science to produce decision tools to help predict and manage resources regionally. And in my testimony, I hope—I was trying to make the case that we are on the threshold of being able to do that with regional fidelity that is unprecedented, and the U.S. is in the leadership in this arena. If you think about water in California, it is dependent on snow. It is dependent on precipitation. It relates to El Niño and La Niña cycles that Mr. Rohrabacher was talking about.

Mr. COSTA. We used to think that droughts lasted five to seven years. Today, by new studies that have come out, it is estimated historically that droughts have lasted anywhere from 50 to 70 years because of new science that has come forth.

Dr. KILLEEN. There are long-term droughts that have lasted longer than that in the continental United States in the historical record, and so we need to understand the factors, the harbingers that will—would change materially the provision of water to states like California. It means a regional decision support system, which is going to be derived from satellite data sets, data resimulation into numerical models, large computational models that have fidelity and that are tested continued against reality to make sure that they work and they are real. And these are the sort of important scientific underpinnings for management of natural resources, such as in your state.

Mr. COSTA. Thank you.

Mr. SCHWARZ. Thank you, Mr. Costa.

The gentlelady from Texas, Ms. Jackson Lee.

EFFECTS OF DECREASED EARTH SCIENCE FUNDING

Ms. JACKSON LEE. Thank you, Mr. Chairman, very much, and I thank the Ranking Member for I think what is a very important hearing. I think, as I look at the panelists whose testimony I will review, and I thank you for your indulgence of the several meetings, and even meetings in the anteroom with constituents. But Mr. Diaz, let me thank you very much for your service. And I think I will focus more particularly on some of the others. And I will ask a broad-based question.

Let me just let it out of the bag. I am a strong supporter of the human space flight and the Shuttle. I come from Houston. But I have been on this committee now for going on 10 years, or maybe almost 10 years. I have never stepped away from the valued importance of Earth science. And it disheartens me to know that our government is in the horns of a dilemma in borrowing from Peter to pay Paul, unnecessary, from my perspective. Now it seems to me that there is dynamic research going on in the private sector, academic institutions. So I am going to be asking broad-based questions. I want to know if that is the case. I want to know what value it is to have a government entity actively engaged in Earth science, you know, how does that—you know, we have always heard the story that the Internet generated out of DOD and look where we are today. And somebody might want to—I think someone is smiling because of who may have taken credit or not. But the point is that we know that it was a government-based energy that came forth.

So I want these broad-based questions which is, you know, how are we harmed if we diminish our efforts in Earth science. That is the first one. That perilous route are we now taking by the government's major cuts that we are now experiencing and suffering in the Earth science area? Mr. Diaz has to defend a budget that I think is non-defendable. And then, in particular, I want to speak about what Earth science NASA has been able to do and that is dealing with the NASA Global Precipitation Management satellite and the fact that we have had to cancel or scale back most Earth science missions, this satellite is to be coordinated with launches of related satellites by other nations, was first scheduled to be launched in 2007, currently launching in 2010, and would be considered on schedule. Obviously, it is not on schedule because of the budget.

The other point that I wanted to be pointed about, I went to Sri Lanka right after the tsunami and walked the streets, heard the stories of our government officials, meaning embassy, heard how they got a call, how they heard and thought that someone in Hawaii had heard something but had no ability to communicate it, and so it was an enormous tragedy, and to understand that NASA has the capacity, potentially, to detect that kind of, forgive me for being a non-scientist, that kind of disturbance, that kind of disruption, that kind of notice that might have been given to those ocean-based persons, and they could have had a greater saving of life.

So there is Dr. Moore, Dr. Killeen, I believe, Dr. Solomon, Dr. McNutt, Dr. Williamson, and is there—is that, Dr. Williamson, going that way. Would you kindly—my light is still green, but I am going to yield to you. If you could just quickly go down the line with those bullet points: the perilous route that we are taking, how we are suffering with not doing this Earth science at the pace I think we should.

Thank you, gentlemen and lady.

Dr. MOORE. Yeah, I think these cuts are significant, and therefore, they are damaging. You could not have significant cuts and not have damage. An analogy that I have used earlier I would like to return to. The United States government helps ensure the medical care for this country through the National Institute of Health. The NIH funds fundamental research in medicine throughout the country, both at universities and in the private sector and in national labs. NASA plays, in a unique way, that same role. The uniqueness is in the Earth—the ability to have the Earth observing from satellites. And so when we begin to cut into that research base, we do damage.

Ms. JACKSON LEE. Thank you.

Dr. Killeen.

Dr. KILLEEN. I would say that——

Ms. JACKSON LEE. And now we are on the beige light. The next light is red, so we—and it is facing me, not you, but—so that is——

Dr. KILLEEN. I think the Nation does stand to be damaged with a reduction in—major reduction in support in the Earth sciences and the NASA contributions there. You asked how will we be harmed if this—it is hard to be precise in quantitative terms, but we are a knowledge-based society, and we will be reducing the amount of knowledge we will have in the future to support decision-making. If you only think about the ozone hole and what that meant to us and the fact that NASA, in fact, was the agency that allowed—it was provided the smoking gun that gave us the relationship between chlorine—man-produced compounds and loss of ozone, and we were able to understand that problem and then react to it with international protocols. One gets a sense that this is an important capability that we need to sort of maintain for our community.

I am most concerned about the pace of change. Rapid change in an enterprise like this can cause irrevocable damage, not only to the building systems but also to the human capital and infrastructure for Earth science research.

Ms. JACKSON LEE. Dr. McNutt? Oh, Dr. Solomon.

Dr. SOLOMON. Let me give a quick answer on top of Dr. Killeen, and then Dr. McNutt can respond.

I think the danger in not carrying forward as ambitious and thoughtful a program in Earth science as we can afford is two-fold. One is knowledge, as others have said. And we have heard examples all morning and into the afternoon where space gives us an opportunity to track hurricanes based—you saw firsthand the tragic consequences of a tsunami where having in place more sensors and the capability to convey warnings would have saved lives. The same is true with volcanic eruptions. The same may be true some day with earthquakes themselves. So that knowledge is an opportunity cost that is very hard to gauge. But the more we have, the better we can deal with the inevitable changes to our—to Earth. We are not going to stop tsunamis, and we are not going to stop volcanoes from erupting, but to know that they are going to happen and to have warning systems in real time can make a real difference.

The other loss that we could sustain if we cut back, and any program as ambitious as Earth science and space or human space flight, which is something that you follow, is the loss of interest of the next generation. I think these programs are enormously appealing, and the young people who are choosing what careers to go into, they are very smart, and they can see——

Ms. JACKSON LEE. Trends.

Dr. SOLOMON.—trends. They can see where there is going to be interesting things to do 10 or 20 years from now and where things are shutting down.

Ms. JACKSON LEE. I think that is the greatest devastation. You are absolutely right.

Dr. McNutt.

Dr. MCNUTT. Yes. I wanted to briefly comment on the tsunami and NASA's role in it. Your reference was indeed right that the adjacent altimeter satellite was in the right place at the right time, that it detected the tsunami wave. That was, I think, a chance occurrence. One couldn't count on that as a reliable warning system, and I think you have already heard testimony of systems that could be put in place.

I will mention, however, another NASA contribution, and that was in the immediate aftermath of the tsunami, NASA satellites were able to record, with quite high fidelity, the damage that was done by the saltwater that affected the crops, the forests in the area. This kind of information was important for assessing what the economic damage would be and where help most needed to go in order to bring relief to the affected populations. So I don't think NASA can be blamed for lack of a warning system, but I think they should get some credit for the relief efforts.

Ms. JACKSON LEE. I was not intending to blame. I was saying that enhancing what they had could, in fact, have put us in a better position that Earth science is valuable.

Dr. Williamson, thank you.

Dr. WILLIAMSON. Yeah, well, I—as you have noticed from my testimony, I tend to focus on the more practical aspects of whether the outcomes of research and so forth. And it is certainly true that our store of previous research and knowledge that we have built up over that period has contributed tremendously, not only to our quality of life, but directly to the economy. And I notice that we have suffered a—somewhat of a reversal in the economic growth in the last quarter over the previous quarter.

One of the things that needs to be thought through in these efforts is how the Earth science program actually contributes to the economy. And I think it is a substantial contribution and certainly NASA's research, starting at the beginning, basically, it is basic research that provides the foundation for these wonderful applications that we all benefit from really needs to be continued and at a reasonable important—you know, pace, if you will, and amount.

Ms. JACKSON LEE. Mr. Chairman, I want to thank you very much, one, for your indulgence. If I might just ask unanimous consent to have my statement, my full statement placed in the record and just place on the record the fact that this is a very important hearing, particularly for those of us who are advocates of space exploration, and to say that we are not advocates of borrowing from Peter to pay Paul or advocates from taking from one program or another.

I happen to be a strong supporter of the International Space Station, and I think there is a wonderful partnership, potential partnership between Earth science research and the Space Station. The most devastating aspect of the testimony of all of the distinguished gentlemen, including Mr. Diaz, who I thank for his service, is that we are killing—to use a very strong and harsh term, we are killing the spirit of the future scientists of America, and I think we would do a disservice to do that. I hope we can find a way in this bipartisan Committee to restore some of the funds for Earth science.

I thank the gentleman very much.

Mr. SCHWARZ. Without objection.

Mr. Diaz, Dr. Moore, Dr. Killeen, Dr. Solomon, Dr. McNutt, Dr. Williamson, this has been a very edifying morning for all of us, for me especially. I appreciate your coming to testify before the House Science Committee. And if there is no objection, the Committee is adjourned.

[Whereupon, at 1:10 p.m., the Committee was adjourned.]

Appendix 1:

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Alphonso V. Diaz, Associate Administrator, Science Directorate, NASA

Questions submitted by Chairman Sherwood L. Boehlert

Q1. You stated at the hearing that "We are in conversation with NOAA very frequently, and we do have agreements in place for many of the elements.. . . [I]f NOAA were sitting here today, they would recognize. . .the things that we are talking about transferring or the things we are talking about doing jointly." Please provide any Memorandum of Understanding or other document relating to NASA working jointly with NOAA, or transferring projects or project elements to NOAA.

A1. The NASA–NOAA partnership is governed by the NASA–NOAA Basic Agreement, with annexes to address specific areas. The two agencies are currently working on an annex to cover research and operations transitions that are now under study. NASA and NOAA also have an agreement with CNES and EUMETSAT on an operational ocean topography mission. Copies of these agreements are attached.

Q2. You also said at the hearing, "What we don't have in place is an overall strategy that is articulated that does what I have mentioned." Are there any plans to articulate such a strategy? Who would have to approve such a strategy at NASA, NOAA and the White House?

A2. OSTP has provided specific guidance on the incorporation of Landsat-type instruments into the NPOESS program as the means to secure long-term continuity of land cover remote sensing. More broadly, the Executive Branch has developed and approved a strategic plan for an Integrated Earth Observation System as the U.S. contribution to the Global Earth Observation System of Systems. This plan primarily covers the operational components of a national observing system. The research components are coordinated through various interagency programs, including the Climate Change Science Program. Both operational and research observation plans are coordinated through the U.S. Group on Earth Observation (USGEO) of the Committee on Environment and Natural Resources of the National Science and Technology Council. The USGEO is co-chaired by officials from OSTP, NASA, and NOAA. In addition, senior officials from both NASA's Science Mission Directorate and NOAA are Principals of the Committee on Environment and Natural Resources and must sign off on CENR plans.

Q3. The first recommendation of the Academy panel is that the Global Precipitation Mission (GPM) be launched without delay. It is unclear whether GPM is funded at an adequate level in the FY06 budget proposal to be able to achieve this launch schedule. The FY 2005 budget request reduced the funding for GPM to allow for a 2012 launch date. The FY 2006 budget maintains this reduced funding level, despite stating that GPM is now scheduled to launch in 2010. Is GPM funded at the level to allow for a 2010 launch? How much funding must GPM have to ensure that the mission launches in 2010?

A3. GPM is a mission in formulation, and therefore does not have a fixed life cycle cost. In FY 2006, NASA has requested $24 million to support a 2010 launch date.

Q4. As part of the procurement for the GPM Microwave Imager (GMI), does NASA plan to include two high-frequency channels (specifically, 166 and 183 GHz) for the instrument? If not, why not?

A4. The two high-frequency channels are options, as is a second GMI unit, in the current contract with Ball Aerospace Technologies Corporation to develop and build the GPM Microwave Imager (GMI). The decision on exercising the high frequency option will be made based on scientific merit and cost during the next several months.

Q5. In your testimony, you mentioned that NASA is participating in a Joint Research to Operations Working Group with NOAA. What is NASA's funding level for this working group? Please describe the results of the interactions between NASA and NOAA within this working group so far.

A5. The R&O Transition Plan being formulated by the JWG includes a systematic approach to develop Capability Implementation Plans for each research capability that is identified for transition to operations. The budget associated with transitioning the capability will be included in the Capability Implementation Plan for senior management review. The agencies will determine how transition cost will be allocated, based on the approved version of the Capability Implementation Plan. The funding for the working group so far has been to support the personnel in the working group. There are 20 active members of the working group (10 from NOAA and 10 from NASA). Even though the civil servant support has been deemed part of the normal course of the job, the value of the civil servant time and contractor support to this effort is valued at ~$400 thousand.

An ad hoc Joint Working Group (JWG) was organized and has been holding regular bi-weekly meetings since October 2004. Dr. Colleen Hartman (NOAA) and Dr. Mary Cleave (NASA) are the senior managers responsible for oversight of the ad hoc JWG. Gary Davis (NOAA) and Ron Birk (NASA) are the co-leads for the ad hoc JWG.

The following are results for the NASA and NOAA interactions through the ad hoc Joint Working Group to date:

- Formulated and documented an organizational and performance framework for this bilateral R&O activity, including agency and user community roles.
- Formulating, documenting, and coordinating joint agency concurrence to a plan for implementing the R&O transition process that includes seeking independent evaluation and reviews of the plan.
- Defining, documenting, and facilitating the process for development and approval of Capability Implementation Plans (CIP) for transition or use of specific research and operational capabilities.
- Coordinating identification of candidate transition capabilities by integrating agency and user community input.
- Forming Capability Implementation Planning Teams to prepare Capability Implementation Plans for candidate transition capabilities.
- Recommending respective agency membership on Capability Implementation Planning teams.
- Formulating a process for JWG reviews of individual Capability Implementation Plans (CIP).

The NASA Applied Sciences Program is focused on extending the results of Earth science research to serve in operational systems through partnerships with federal agencies and national organizations and is supporting the JWG.

Q6. In your testimony you mentioned that one way NASA and NOAA have worked together was funding the National Academy of Sciences (NAS) 2003 report, Satellite Observations of the Earth's Environment, Accelerating the Transition from Research to Operations. *One of the major recommendations from that report is that "a strong and effective Interagency Transition Office for the planning and coordination of activities of the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA) in support of transitioning research to operations should be established by and should report to the highest levels of NASA and NOAA." Does NASA support establishing and Interagency Transition Office as described in the NAS report? If so, what is NASA doing to establish the Office? If not, why not?*

A6. NASA and NOAA are actively engaged in establishing the Joint Working Group on Transition Research and Operations (R&O). This joint working group includes senior management from both agencies and a structured approach to involve key personnel for each of the areas for transition. The approach is to establish agreement on specific capabilities to be transitioned and to assign teams with representatives from NASA and NOAA to participate in developing the Capability Implementation Plans.

Deliberations on the recommendations from the NAS 2003 report to establish an Interagency Transition Office led to the development of the Joint Working Group on Transition of Research and Operations. The JWG is formulating a Transition Plan to systematically:

a. Identify the candidate capabilities for transition (including community participation).
b. Establish teams with the appropriate knowledge to develop Capability Transition Implementation Plans.
c. Formulate the detailed Capability Transition Implementation Plans with information on schedule, budget, resource requirements, and benefits to the Nation.
d. Senior review of the Capability Transition Implementation Plans for subsequent decisions on budget and resource allocations.

This approach optimizes the capacity of involving the appropriate representatives for the functions of:

a. Establishing and evolving the processes for transitions.
b. Identifying the candidate capabilities for transition.
c. Developing the capability transition implementation plans.
d. Reviewing the capability implementation plans.
e. Identifying and allocating budgets and resources to implementation the capability transitions.

Q7. What is the status of the NASA Earth Science and Applications from Space Strategic Roadmap and what are the main conclusions of their work so far?

A7. The NASA Earth Science and Applications from Space Strategic Roadmap Committee completed its work with the submission of its report to NASA on May 22, 2005. The NRC has separate congressional direction to look at NASA science issues, including the six science roadmaps. NASA has since provided to the NRC the science roadmaps received on May 22. In June, members from each of the six science committees will brief the committee results to the NRC. The NRC will plan to provide a report or other input on the science roadmaps to NASA by August 1, 2005.

The concepts and recommendations identified by the Earth Science and Applications from Space Strategic Roadmap Committee are advice to NASA and are subject to review by the NRC. The following are some of the concepts put forward by the Roadmap Committee:

1. In addition to scientific objectives that motivate specific missions and modeling, the committee identified integration objectives that motivate the synergistic networking of systems.
2. The committee has identified a metric, the measurement maturity index, to assist in the planning and management of investigations, assess their potential transition to operations, and as an aggregate measure of the balance of investments in a research area. While needing more development, the committee believes this could be developed into a useful tool for planning future investigations.
3. The committee identified a preliminary mission timeline, along with an approach (called "awareness clusters") to organizing and building over time the integrated capacity to observe and model the Earth system.

The near-term recommendations of the Committee include:

1. Complete the current, approved NASA program in a timely fashion.
2. Begin advanced planning for several near-future missions identified in the committee's timeline.
3. Begin advanced planning for the first "awareness cluster," including the technologies, missions, models, networks, and educational and international cooperation opportunities that support the science focus of the cluster.
4. Start at least one new mission in FY 2007 or FY 2008 and the others as soon as possible after that.

Q8. The National Academy of Sciences interim report stated: "The committee is concerned that a significant reallocation of resources for the research and analysis (R&A) programs that sustain the interpretation of Earth science data has occurred either as a result of the removal of the 'firewall' that previously existed between flight and science programs or as an unintended consequence of NASA's shift to full-cost accounting." Please describe the extent to which NASA has reallocated funding for the Earth Science R&A programs, and explain why this has occurred.

A8. In recent years, NASA's research budget has been largely stable. The research and analysis (R&A) program, one of about 60 projects within the Earth-Sun Research Program, has been particularly stable, with minimal year-to-year fluctuations. There has been only one significant modification to this program in recent years. The transition from "business-as-usual" to "full cost accounting" in FY 2004 led to an increase of approximately 20 percent in the R&A budget over the FY 2003 budget, but the imprecision associated with this transition led to an increase in requirements for center-related funding that was approximately 50 percent greater than the increase in funds, leading to an effective reduction in purchasing power of the R&A program of the order of 15 percent. The shortfall in FY 2004 impacted contractors at the NASA centers and the broader research community. In FY 2005, the R&A program was adjusted to accommodate these full cost transitions and per the mid-year operating plan, is $10 million higher than the final FY 2004 operating plan.

MEMORANDUM OF AGREEMENT

BETWEEN THE

DEPARTMENT OF COMMERCE

DEPARTMENT OF DEFENSE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FOR THE

NATIONAL POLAR-ORBITING OPERATIONAL ENVIRONMENTAL SATELLITE SYSTEM (NPOESS)

I. PREFACE

On 5 May 1994, the President directed convergence of the Department of Commerce (DOC) National Oceanic and Atmospheric Administration's (NOAA) Polar-orbiting Operational Environmental Satellite (POES) program and the Department of Defense (DoD) Defense Meteorological Satellite Program (DMSP). These two programs will become the National Polar-orbiting Operational Environmental Satellite System which will satisfy civil and national security operational requirements. In addition, the National Aeronautics and Space Administration (NASA), through its Earth Observing System (EOS) efforts, offers new remote sensing and spacecraft technologies that could potentially improve the capabilities of the operational system. The President also directed DoD, DOC, and NASA to establish an Integrated Program Office (IPO) to manage this converged system.

II. PURPOSE

This document constitutes the formal agreement, including roles and responsibilities, between DOC, DoD and NASA, hereafter referred to as "the agencies," to implement the President's directive to establish the National Polar-orbiting Operational Environmental Satellite System (NPOESS).

III. AUTHORITY

This agreement implements Presidential Decision Directive NSTC-2, 5 May 1994, and implements the White House Office of Science and Technology Policy's "Implementation Plan for a Converged Polar-orbiting Environmental Satellite System," dated 2 May 1994. This document provides the necessary authority and responsibility to manage all aspects of the NPOESS. NOAA enters this agreement pursuant to its authority at 15 USC 1525; 49 USC 1463 and 15 USC 313.

IV. NPOESS PROGRAM ORGANIZATION AND RESPONSIBILITIES

The NPOESS program will satisfy the U.S. Government's fundamental civil and national security requirements for collection and distribution of operational polar satellite-based, remotely-sensed meteorological, oceanographic, climatic, and space environmental data. The NPOESS will be composed of four components: spacecraft and sensors; launch support; command, control, and communications; and user interface. Management and implementation of the NPOESS program will be accomplished by the Integrated Program Office (IPO) under a triagency Executive Committee (EXCOM). The responsibilities and functions of these organizations are as follows:

A. Executive Committee

The Under Secretary of Commerce for Oceans and Atmosphere, the Under Secretary of Defense for Acquisition and Technology, and the NASA Deputy Administrator will form the NPOESS EXCOM. Each EXCOM member will be accountable to the EXCOM for his/her agency's support of the NPOESS. The EXCOM will provide policy guidance; ensure sustained agency support (to include funding); approve the annual budget; approve the NPOESS staffing plan; approve the acquisition program baseline (cost, schedule, performance) and major changes to the baselines as proposed by the System Program Director (SPD); endorse the NPOESS requirements baseline; and approve or recommend approval of modifications or waivers to existing agency policies as they pertain to NPOESS. The EXCOM will also review an annual business plan and approve the Convergence Master Plan (CMP) as defined in Section VII.

B. The Integrated Program Office

The IPO, under the direction and management of the SPD, will be the single functional entity responsible for the planning, budgeting, development, acquisition, launch, operation, and management of the NPOESS. The SPD is ultimately responsible to the triagency EXCOM for NPOESS. The SPD has decision authority for NPOESS matters, subject to the statutory authorities of the designated agencies, and reports to the NOAA Administrator, through the NOAA Assistant Administrator for the National Environmental Satellite, Data, and Information Service (AA NESDIS). Reporting through the AA NESDIS means that the SPD must have the concurrence of the AA NESDIS prior to the SPD making any NPOESS decisions affecting DOC/NOAA/NESDIS. The AA NESDIS has the lead within DOC for resolving issues that arise between the IPO and DOC/NOAA/NESDIS components prior to decisions being made that impact DOC/NOAA/NESDIS/NPOESS. Issues that cannot be resolved by the SPD and the AA NESDIS will be brought by them to the NOAA Administrator for resolution.

The IPO will be a separate entity located within the NESDIS, which is the organizational component in NOAA having responsibility for DOC satellite programs, and therefore, will provide the primary NOAA matrix support for the IPO. The AA NESDIS is responsible for all aspects of the current NOAA Polar-orbiting Operational Environmental Satellite (POES) program through the life of the N and N' satellites to include coordinating POES fully with

NPOESS. In addition, the AA NESDIS has the lead responsibility within the DOC/NOAA to ensure that the IPO and the NPOESS are properly supported and the NPOESS is properly integrated with the NOAA civil environmental satellite remote sensing mission.

The SPD will also coordinate decisions on NPOESS matters that affect DoD with the Assistant Secretary of the Air Force for Space (ASAF/SPACE) to ensure resolution of potential issues or forwarding of issues to the appropriate official for resolution. All NPOESS acquisition decisions made by the SPD that affect DoD will be coordinated with the Air Force Service Acquisition Executive and any related issues resolved prior to decision execution.

During the transition to an operational NPOESS, the AA NESDIS and ASAF (Space), in consultation with the SPD, are responsible for coordinating and integrating the existing POES and DMSP activities with the NPOESS by promoting commonality, developing consistent budget submissions, and ensuring compatibility and interoperability. Further details regarding the relationship between the IPO/SPD and agency organizations/officials affected by or supporting the NPOESS will be described in the Convergence Master Plan.

The IPO shall consist of three functional line offices and an SPD staff operating under the management and direction of the SPD. Functions and responsibilities of the directors are as follows:

(1) The System Program Director (SPD) will:

(a) Direct the converged program and be responsible for financial, programmatic, and technical and operational performance of the NPOESS.

(b) Direct all IPO management functions, centrally control the distribution of all funds appropriated for or transferred to NPOESS and have or delegate final approval authority over all appropriate contract actions as defined in the CMP.

(c) Have final approval of the individuals nominated by the agencies for the positions of the Deputy System Program Director and the three Associate Directors (Acquisition, Technology Transition, and Operations).

(d) Be the Source Selection Advisory Council Chairman for NPOESS major component acquisition.

(e) Have primary responsibility on behalf of the EXCOM member agencies for all NPOESS-specific international agreements to include developing and negotiating terms and conditions to ensure compatibility with NPOESS goals and objectives. The SPD will participate in any activities resulting in U.S. national policy and/or U.S. Government international agreements that impact NPOESS.

(f) Prepare the NPOESS budget consistent with the agencies' internal budget processes. Execute the NPOESS budget in accordance with the approved program baseline.

(g) Participate in and coordinate on all interactions by the agencies with the Executive and Legislative branches regarding NPOESS.

(h) Develop the CMP and annual business plan.

(i) Propose, for EXCOM decision or recommendation, changes to agency policies or procedures as they pertain to the NPOESS.

(j) Approve all NPOESS acquisition documents prior to submission to the designated acquisition agency for action and approve of all acquisition/procurement decisions made below the EXCOM level prior to implementation.

(2) Associate Director for Acquisition (ADA) will:

(a) Be responsible to the SPD for developing, acquiring (including test and evaluation) and fielding the NPOESS components and for launch and early on-orbit checkout.

(b) Conduct developmental activities necessary to support the acquisition program baseline.

(c) Conduct, in concert with the Associate Director for Technology Transition (ADTT), studies to determine the potential impact upon system resources of accommodating new technologies being evaluated by the ADTT.

(d) Prepare the acquisition budget submissions for SPD approval.

(e) Prepare acquisition documents.

(f) Manage the acquisition budget as directed by the SPD.

(g) Ensure effective integrated logistics/life cycle support.

(h) Have final approval of the individual nominated for the position of Deputy ADA.

(3) The Associate Director for Technology Transition (ADTT) will:

(a) Be responsible to the SPD for promoting transition of new technologies that could cost- effectively enhance the capability of NPOESS to meet operational requirements.

(b) Identify and evaluate new technologies which could be transitioned for further development by the ADA.

(c) Seek out, and provide to the ADA for evaluation, opportunities to fulfill operational requirements with flight-proven observation science/research instruments that may also simultaneously satisfy science requirements.

(d) Develop and update annually a strategic plan for technology transition to address unaccommodated Integrated Operational Requirements Document (IORD) requirements and enabling technologies.

(e) Prepare the technology transition budget submission, based on the technology transition strategic plan, for SPD approval.

(f) Manage the technology transition budget as directed by the SPD.

(g) Have final approval of the individual nominated for the position of Deputy ADTT.

(4) The Associate Director for Operations (ADO) will:

(a) Be responsible to the SPD for operation of the NPOESS, which includes: commanding the spacecraft; recovering/analyzing health and status; acquiring telemetry data for trend analysis; ensuring communications for telemetry and tracking; providing a continuous sensor data stream, anomaly support, mission planning, and any necessary ground segment processing (as defined in the IORD) required to effectively interface with the users.

(b) Prepare the operations budget submissions for SPD approval.

(c) Manage the operations budget as directed by the SPD.

(d) Be the interface for operational activities with any international partners contributing to NPOESS in accordance with the appropriate international agreements.

(e) Have final approval of the individual nominated for the position of Deputy ADO.

(5) The SPD Staff will support the SPD in the areas of:

(a) Program Control, which will provide overall NPOESS programming, planning and budgeting functions.

(b) Systems Engineering, which provides system-level coordination of NPOESS engineering and integration activities, technical and cost feasibility analysis of IORD-defined user requirements, and documentation to support milestone decision activities.

(c) User Liaison, which will be the IPO interface for the primary civil and military users of NPOESS data to provide comments or concerns on the ability of NPOESS to meet requirements outlined in the IORD.

(d) External Affairs, which will support the SPD by managing the development and coordination of activities to ensure the IPO effectively interacts with external (both domestic and international) organizations in fulfilling the SPD's responsibilities regarding the NPOESS.

V. AGENCY RESPONSIBILITIES

The lead agency will have the primary role in providing required support for the execution of a specific function under the management of the IPO. Lead agency in this agreement does not mean the total delegation of the activity to that single agency. The agency with the lead for a particular function will provide the Associate Director and core personnel as part of a triagency NPOESS team performing that function using appropriate agency policies, procedures and statutory authorities (with modifications recommended by the SPD to the proper authority or approved by the SPD as appropriate).

A. DOC Responsibilities:

The DOC, through NOAA, will have lead agency responsibility to the triagency Executive Committee (EXCOM) for the converged system. Specifically, NOAA will nominate the System Program Director (SPD), who will be approved by the EXCOM. NOAA will have lead agency responsibility to support the IPO for satellite and ground segment operations; and NOAA will have the lead responsibility for interfacing with national and international civil user communities, consistent with national security and foreign policy requirements. NOAA will also provide the Associate Director for Operations, the Deputy Associate Director for Acquisition, and sufficient personnel (as defined in the NPOESS staffing plan) to support each of the IPO's directorates and functions.

B. DoD Responsibilities:

The DoD will have lead agency responsibility to support the IPO in NPOESS component acquisitions necessary to execute the acquisition program baseline. Acquisition decisions made by the DoD EXCOM member affecting NPOESS will be undertaken with concurrence of the other EXCOM members. The statutory authorities resident within DoD for acquisition and contracting of the acquisition program baseline will be used to carry out this lead agency responsibility. Should other procurements be necessary to support the NPOESS, the SPD will decide how to carry them out, using the acquisition authority of the appropriate agency and will seek the approval of the EXCOM, if necessary. DoD will nominate the Deputy System Program Director and the Associate Director for Acquisition who will be approved by the SPD. DoD will also provide the Deputy Associate Director for Operations, Deputy Associate Director for Technology Transition and sufficient personnel (as defined in the NPOESS staffing plan) to support each of the IPO's directorates and functions. DoD will provide the majority of the acquisition personnel and acquisition infrastructure support to the IPO to include legal, contracting, administration, financial management, and logistics.

C. NASA Responsibilities:

NASA will have lead agency responsibility to support the IPO in facilitating the development and insertion of new cost-effective and enabling technologies that enhance the ability of the converged system to meet its operational requirements. In conjunction with the IPO, NASA will conduct periodic reviews of Mission-To-Planet Earth (MTPE) Projects to determine areas of common interest with the operational requirements and evaluate if and when these areas could be applied to the NPOESS. Also, in accordance with the conditions/principles specified in Appendix 1, NASA will supply additional copies of those NASA research instruments for flight on NPOESS. NASA will provide the Associate Director for Technology Transition who will be approved by the SPD. NASA will also provide sufficient personnel (as defined in the NPOESS staffing plan) to support each of the IPO's directorates and functions.

VI. REQUIREMENTS

An Integrated Operational Requirements Document (IORD) will be the sole operational requirements source from which triagency cost and technology assessments, specification development, and related acquisition activities will be conducted. The IORD shall be updated before each major milestone (see Figure 1). The assembling, evaluating and prioritizing of agency requirements to produce the IORD will be based on the DoD processes described in the 5000 series instructions, as tailored. The requirements process will be independent of the IPO and is designed to ensure each agency's requirements are accountable and traceable to each agency. To this end, each agency will designate a senior official to be its representative to the Joint Agency Requirements Council (JARC) and be accountable for its agency's requirements. Chairmanship of the JARC will rotate between DOC and DoD on a biannual basis. The JARC will resolve any interagency requirements issues. Appendix 2 provides further detail on the requirements process.

The agencies will establish a Senior User's Advisory Group (SUAG), independent of the IPO, representing the primary USG users of NPOESS data. This group will advise the SPD on the needs of the user community and on program decisions related to satisfaction of IORD requirements. This group will be small in number, and consist of at least the NOAA Assistant Administrator for Weather Services, NOAA Assistant Administrator for Satellite and Information Services, the Air Force Director of Weather, the Oceanographer of the Navy, Air Force Space Command Director of Operations, and the NASA Office for Mission to Planet Earth Science Division Director (if any NASA research instruments are used to meet operational requirements). Chairmanship of the SUAG will rotate between DOC and DoD on a bi-annual basis. A single agency will not chair both the SUAG and JARC simultaneously.

VII. NPOESS MANAGEMENT AND PROCESSES

NPOESS management and processes will be further defined and conducted in accordance with the Convergence Master Plan (CMP), which is to be developed by the SPD within 6 months of appointment. The CMP will be submitted to the EXCOM for unanimous approval. The CMP will contain: an Acquisition Management Plan; a Technology Transition

Management Plan; an Operations Plan; a Funding Management Plan; and an integrated Organizational Management Plan. Sections VII. A. through E., below will be fully defined in the CMP. The SPD, in defining the processes, roles and responsibilities will ensure the key tenets derived from NSTC-2 and the Office of Science and Technology Policy Convergence Implementation Plan are adhered to.

The SPD will also develop an annual business plan and a long-range staffing plan. The business plan will address the primary goals and objectives for the year and lay out the principle milestones and the financial plan. It will also address issues to be resolved and the strategy for resolution. Other items will be included in the annual business plan as necessary (e.g., international cooperative efforts and NPOESS status). Building upon the FY 95 Triagency Staffing Plan, the SPD will develop, within 6 months of appointment, a long-range staffing plan for FY 96 and beyond. This long-range staffing plan will address the required number of personnel, appropriate personnel skill sets, grades and unique agency personnel certifications necessary to acquire, operate, or sustain the NPOESS throughout the system's life-cycle.

A. Acquisition Management Plan

OMB Circular A-109, DoDD 5000.1 and 5000.2 (as tailored) will form the basis of the NPOESS major system acquisition (see Figure 1), which will be carried out using DoD acquisition and contracting authority. The DoD component acquisition executive will be the NPOESS Source Selection Authority for NPOESS major component acquisitions. The agencies agree that the NPOESS acquisition is presently in Phase 0 with a Milestone I decision scheduled for approximately the fourth quarter FY 95/first quarter FY 96. An Acquisition Management Plan will be developed to explain the entire acquisition process from beginning to end and will:

- Address threat projections, life-cycle costs, integrated logistics support, cost-performance-schedule trade-offs, affordability constraints, and risk management at each milestone.

- Ensure acquisition strategies and program plans are appropriately tailored to accomplish program objectives and control risk.

- Ensure the acquisition process accommodates the triagency nature of the NPOESS.

- Ensure independent cost analyses are conducted using the structure of the Office of the Secretary of Defense Cost Analysis Improvement Group with NOAA and NASA membership.

B. Technology Transition Management Plan

The NPOESS technology transition management plan will identify and promote processes to foster development of promising new technologies which will enable new operational capabilities as defined in the IORD or enhance existing operational capabilities as delineated in the IORD. The technology transition management plan will be defined in detail in the CMP and developed in accordance with the following guidelines:

- The office will promote relationships among industry, academia and Government organizations to ensure the IPO reaps maximum benefit from ongoing developments and will promote new developments where it is deemed beneficial or necessary to satisfy objective IORD requirements.

- The office will promote the infusion of new technology into NPOESS to advance its capability to meet user requirements. The office will monitor research activities of various organizations (NASA, DoD, universities, etc.) for applicability and, where warranted, will recommend and conduct further study and/or demonstrations with SPD approval and funding by the IPO.

C. Operations Plan

The NPOESS will be operated to ensure data are supplied to the NPOESS users for further specialized data processing as stated in the IORD. The SPD will develop an operations concept. The operations concept and any required implementing documentation will be submitted to the EXCOM for approval as part of the CMP. NPOESS matters not under their authority (e.g., military operations) will be forwarded to the proper authorities for action/approval as agreed upon by the EXCOM. The operations concept will address day-to-day operations of the NPOESS, including the development of user interfaces and analysis of data to ensure the converged system is capable of meeting its performance requirements . The operations concept will specifically address Command, Control, and Communications (C3) operations (to include any agreements needed to implement changes in C3 authorities and responsibilities as necessary during times of crisis or war). The operations concept will also reflect the NPOESS launch-on-failure, or anticipated failure, policy needed to maintain uninterrupted availability of critical data. The operations concept will address data retrieval, ground pre-processing, distribution, launch call procedures, transition from early on-orbit checkout to operational status, and any modification to standard operating procedures which may be needed. The operations concept will ensure:

- The NPOESS will establish a civilian interface to national and international civil users to promote its open character.

The NPOESS will be able to implement data denial should the Secretary of Defense (SECDEF) direct, after consulting with the Secretaries of Commerce (SECCOM) and State (SECSTATE). In that regard, the operations concept will specifically address the process for consultation between SECDEF, SECCOM, and SECSTATE and the implementing process at the ground site(s) and the timelines. In the event that a foreign satellite is part of NPOESS, the operations concept will also include the details of data denial implementation of any U.S. instruments on a foreign satellite (e.g., EUMETSAT's METOP series) in accordance with applicable agreements.

- NOAA, through NESDIS, will provide the primary Satellite Operations Center (SOC) infrastructure.

- DoD will provide a mission capable backup SOC at Falcon AFB, Colorado.

- NOAA Command and Data Acquisition stations and elements of the USAF Satellite

Control Network (AFSCN), as appropriate, will be utilized to provide C3 and mission data recovery support for NPOESS and the primary and backup SOCs.

Further, the IPO will develop and present a plan to the EXCOM for the early transition to a joint agency C3 architecture. This will enable transition of the operation of the current POES and DMSP satellites to the IPO as soon as practical. This transition is envisioned to occur in the 1998 time frame to coincide with the DoD's original plans to close dedicated DMSP command and control sites at Fairchild and Offutt AFBs. The USG role in the C3 of the METOP system (space and ground segment) will be included. Furthermore, operation of the current POES and DMSP satellites will be transitioned to the IPO as soon as practical. The NOAA SOC will be used for C3.

D. Funding Management Plan

The process used to fund NPOESS (to include the process for ensuring appropriated funding flows to the IPO) will be defined in detail in the CMP and will contain the following key tenets:

- Each agency's funding will be based on total program cost and common and unique requirements. Since NASA is not an operational agency, the NASA contribution will be limited to funding as specified in Appendix 1.

- A 50/50 cost sharing approach is used for all near-term common activities--the agreed upon DoD and DOC FY 96-01 funding profiles are contained in Figure 2.

- The IPO will budget funds to be applied to technology efforts in support of the technology transition strategic plan.

- Unique agency requirements specified in the IORD will be funded by the appropriate agency.

- For common data products, if an agency's more stringent requirements are determined to be a significant cost driver, then the additional funds required will be provided by this agency.

- All impacts to NPOESS to accommodate payloads which do not satisfy IORD requirements will be funded by the requesting agency.

- Cost sharing will be reassessed, at a minimum, prior to each acquisition milestone review.

E. Organizational Management Plan

Organizational management for the NPOESS will be addressed in the CMP and will include:

- The relationship between the IPO and the requirements process and requirements organizations.

- The relationship between the IPO and any external organization which provides primary support to the IPO (e.g., NESDIS, Air Force, Navy). The SPD will decide to what extent specific functions will be performed by the IPO or will be matrixed from agency offices external to the IPO, taking into account existing agency capabilities and the triagency nature of the NPOESS.

- The processes for personnel management to include performance reporting and succession planning.

- Security classification guidance for the NPOESS program, to include which classification authorities and procedures will be used.

VIII. EFFECTIVE DATE/AMENDMENT/TERMINATION

This agreement shall become effective when it has been signed on behalf of the three signatory agencies.

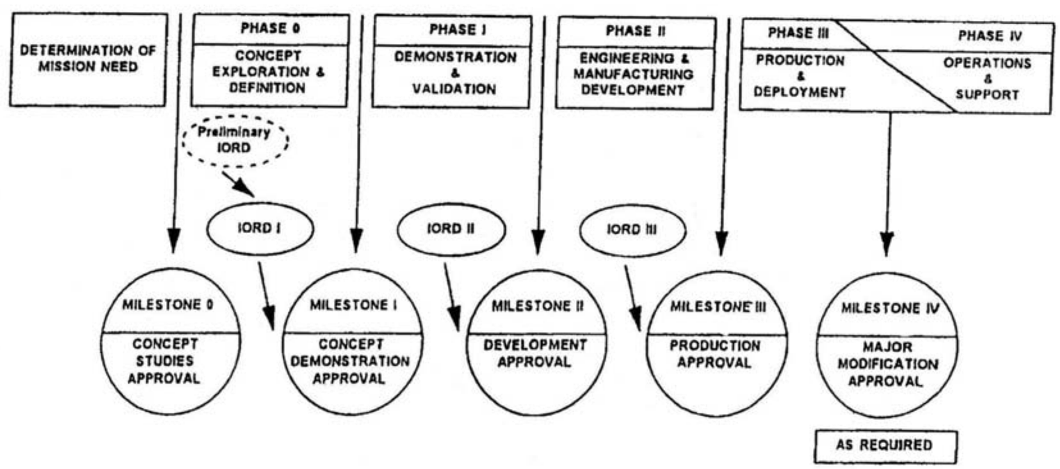
A review of this Memorandum of Agreement will occur within 3 years and on a 4-year cycle thereafter by an EXCOM approved committee. A specific topic to be addressed during the initial review will be the relationship of the IPO and the SPD to the NOAA organizational structure with particular attention to NESDIS and the relationship of the SPD to the NESDIS AA.

This MOA may be amended/terminated at any time by the mutual written consent of the parties hereto. Any party may terminate this agreement by giving at least 6 months prior notification to the other parties. Should it be necessary to terminate the agreement, appropriate notification will be made to the White House and the relevant Congressional committees.

Secretary of Commerce	Secretary of Defense	NASA Administrator

Figure 1

Acquisition Milestones & Phases



Note: The NPOESS Acquisition will follow the DoD acquisition (as tailored) and terminology

APPENDIX 1

TO

NPOESS MOA

CONDITIONS FOR SUPPLYING NASA RESEARCH INSTRUMENTS TO THE CONVERGENCE OPERATIONAL (NPOESS) PLATFORM

If the decision is made to fly a NASA instrument on the (NPOESS) platform instead of continuing to fly it on a NASA research spacecraft, because the research instrument will meet the convergence operational requirements in a cost-effective manner and continues to provide data so as to fulfill primary NASA research mission requirements, NASA will provide additional copy(s) of the instrument for flight on the NPOESS platform at no unit cost to the NPOESS program. This policy of supplying instruments at no cost will apply as long as NASA continues to need the data supplied by the instrument to fulfill its primary research mission objectives. As part of the transfer of the NASA instrument to the NPOESS platform, the NASA scientific research requirements associated with that instrument will likewise be included in their entirety in the formal set of operational program requirements listed in the Integrated Operational Requirements Document (IORD; possibly as an annex) and removed from the IORD when the NASA instrument no longer flies on the NPOESS. Modifications to an instrument will only be considered if there is no loss of NASA science. The cost sharing by the three agencies for modification and/or accommodation of the NASA research instrument will be agreed upon by the agencies as part of the decision to fly the instrument on the NPOESS platform(s).

The term "NASA research instrument" refers to those NASA instruments which have been developed and flown in space to provide data that are necessary to fulfill NASA scientific research objectives (e.g., provide data to answer questions regarding global change as defined by the Intergovernmental Panel on Climate Change (IPCC) and incorporated in NASA's research program objectives).

Figure 2

Budget & Agency Contributions

	FY96	FY97	FY98	FY99	FY00	FY01	TOTAL
BUDGET	78.0	120.0	187.0	340.2	372.7	328.1	1426.0
DOC	54.0	78.2	131.4	146.5	162.5	140.4	713.0
DOD	24.0	41.8	55.6	193.7	210.2	187.7	713.0

- FY95 IPO BUDGET IS 23.6 M (DOC 16.0M / DoD 7.6 M)
- AGENCIES AGREED TO 50/50 SPLIT OVER FYDP
- BUDGET FIGURES WILL BE REFINED AFTER PHASE 0 STUDIES

APPENDIX 2

TO

NPOESS MOA

REQUIREMENTS PROCESS

An Integrated Operational Requirements Document (IORD) will be the sole operational requirements source from which triagency cost and technology assessments, specification development, and related acquisition activities will be conducted. The requirements process will be independent of the IPO and is designed to ensure each agency's requirements are accountable and traceable to each agency. Two distinct bodies have direct responsibility for the development and approval of the NPOESS IORD. These bodies are the Joint Agency Requirements Group (JARG) and the Joint Agency Requirements Council (JARC).

The JARG is the interagency group responsible for developing the NPOESS IORD and administering the IORD approval process. JARG members representing triagency requirements will come from HQ Air Force Space Command, Office of the Oceanographer of the Navy, Air Force Directorate of Weather, NOAA/National Environmental Satellite, Data, and Information Service (NESDIS), NASA Goddard Space Flight Center (GSFC), National Weather Service (NWS), the Office of Oceanic and Atmospheric Research (OAR), National Ocean Service (NOS), National Marine Fisheries Service (NMFS) and the NASA Office for Mission to Planet Earth (MTPE). Additional JARG membership will come from Air Force, Navy, Army, NOAA and NASA, as required. The HQ Air Force Space Command, NOAA/NESDIS and NASA/GSFC will be the JARG points-of-contact responsible for administrative support associated with the IORD. Through Tri-Agency IORD development, the JARG will: harmonize and document similar interagency operational requirements; identify and document agency-unique operational requirements; document requirements issues (if any); prepare the IORD for JARC approval and document for JARC decisions any requirements issues. The JARG will then release the draft NPOESS IORD for appropriate agency review/comment. The JARG will resolve draft comments and develop the final IORD for release to all agencies for review/approval. The final IORD will be staffed through each agency's IORD approval authority. The JARG will also develop a requirements master plan for JARC approval which details the process necessary to execute this appendix. DoD policies and procedures are the basis for this requirements process. NASA science requirements will be included in the IORD as stated in Appendix 1 to this MOA. The JARG will be chaired on a rotating (biennial) basis between DOC and DoD. The chair is responsible for all JARG administration.

The JARC is the senior interagency body responsible to approve the NPOESS IORD. The JARC will resolve all JARG documented interagency requirements issues not solvable at a lower level. JARC membership will consist of the Vice Chairman of the Joint Chiefs of

Staff for DoD, the Deputy Under Secretary of Commerce for Oceans and Atmosphere, and the Associate Administrator for Mission to Planet Earth for NASA. In addition, other agency representatives may attend the JARC meeting as required. After JARC approval, the IORD will be forwarded to the EXCOM for endorsement.

Basic Agreement
Between the
National Aeronautics and Space Administration
and the
U.S. Department of Commerce
Concerning
Collaborative Programs

The U.S. Department of Commerce,

and

The National Aeronautics and Space Administration (hereinafter referred to as NASA),

RECOGNIZING the 1964 and 1973 Basic Agreements between the U.S. Department of Commerce and NASA; and

RECOGNIZING the role of the National Oceanic and Atmospheric Administration (hereinafter referred to as NOAA) of the U.S. Department of Commerce in carrying out the operational environmental satellites programs of the Department of Commerce; and

RECALLING the FY 1993 NOAA Authorization requiring a strategic plan with NASA addressing the development, procurement, and operation of the Department of Commerce environmental satellite program; and

NOTING the responsibilities, the missions, and the extent of cooperation of NASA and NOAA in the area of environmental satellite programs; and

REAFFIRMING the need to apply, in a cost-effective manner, the specialized technical, scientific, and operational expertise of NOAA and NASA to the enhancement of U.S. capabilities to forecast environmental conditions and better understand our global environment;

HAVE AGREED as follows:

Article 1

PURPOSE AND SCOPE

1.1. This Agreement defines the general principles and guidelines which will govern the pursuit of opportunities for collaboration between NOAA and NASA (also referred to as "the parties") in areas related to environmental satellite programs, specifically including those activities related to the development of spaceborne capabilities (both the development of new instrumentation and flight opportunities and enhancements to existing systems) and data and information systems, the coordination of research and analysis activities, and other areas of collaboration.

1.2. This Agreement supersedes the NOAA-NASA Basic Agreement of 1973, in regard to the general provisions which are not specific to either the Polar-Orbiting Operational Environmental Satellite (POES) or the Geostationary Operational Environmental Satellite (GOES) program.

1.3 This Agreement establishes mechanisms for regular consultation between the two agencies to encourage a closer working relationship and enhance coordination and promote cooperation.

Article 2

AUTHORITY

2.1. NASA's authority to enter into this Agreement is found in Section 203 (c) of the National Aeronautics and Space Act of 1958, as amended 42 U.S.C. 2473 (c)(5) and (6), and Section 1503 of the Federal Acquisition Streamlining Act of 1994, 10 U.S.C. 2311.

2.2. NOAA's authority to enter into this Agreement is found in the Weather Service Organic Act, 15 U.S.C. 313, and 15 U.S.C. 1525.

Article 3

BASIC RESPONSIBILITIES

3.1. NOAA's mission is to describe and predict changes in the Earth's environment, and conserve and manage wisely the Nation's coastal and marine resources to ensure sustainable economic opportunities. NOAA is responsible for creating and disseminating reliable assessments and predictions of weather and climate and, in this connection, for maintaining continuous operational satellite observations critical for warnings and forecasts.

3.2. NASA is responsible for the conduct of certain U.S. aeronautical and space research activities, the development of new technologies to support NASA's research programs and, where appropriate, facilitating the transition of those new technologies to NOAA. One of its objectives is to understand the total Earth system and the effects of natural and human induced changes on the global environment.

3.3. The participation of the parties in this Agreement is subject to the availability of appropriated funds.

Article 4

COLLABORATIVE ENDEAVORS

4.1. Where appropriate, and in concert with Article 3, projects shall be pursued on a collaborative rather than a single-agency basis if the project:

1) Is of mutual benefit to NOAA and NASA in fulfilling both agencies' requirements and a joint effort is more valuable than single-agency effort;
2) Results in cost savings to the U.S. government for accomplishing specific activities; or
3) Results in increased capability of NOAA and NASA to accomplish program objectives; and
4) Is provided by law.

4.2. NOAA and NASA shall pursue the following goals in developing joint collaborative projects:

1) Improving the knowledge of environmental processes, especially meteorology, climatology, oceanography, land processes, ecology, space environment, and atmospheric science;
2) Improving the observational capabilities of operational and research satellite systems;
3) Improving the acquisition, processing, distribution, archiving, and use of environmental data and information;
4) Improving the acquisition, processing, and distribution of search and rescue and data collection information; and
5) Reducing costs for new observational satellite systems.

If the parties determine to fly an instrument from NASA's research program on a NOAA spacecraft instead of continuing to fly it on a NASA research spacecraft, (because the research instrument will meet the operational requirements in a cost-effective manner and continues to provide data so as to fulfill primary NASA research mission requirements) NASA will provide the first instrument at no unit cost to NOAA. The provision of subsequent instruments by NASA will be in accordance with mutually agreed terms and conditions.

4.3. Agreements for Specific Collaborative Projects:

4.3.1. Separate agreements shall be concluded for each collaborative project, and these agreements may include parties other than NASA and NOAA. These agreements should reflect the criteria identified in Article 4.2.

4.3.2. While the details of these separate agreements for specific NOAA/NASA collaborative endeavors will vary, all such agreements shall stipulate, at a minimum, a formal annual exchange of programmatic requirements, funding arrangements and budgetary estimates, performance status and other related information that ensures proper interagency coordination.

4.3.3. A list of program-specific agreements currently in force will be maintained as Annex I of this Agreement.

Article 5

NOAA-NASA PLANNING COORDINATION COUNCIL

5.1. A NOAA-NASA Planning Coordination Council (NNPCC) shall be established to authorize new activities and to ensure the regular and systematic implementation of previously authorized collaborative projects. The NNPCC shall meet at least twice a year. The NNPCC shall, at a minimum:

1) Review and evaluate current joint projects;
2) Discuss and authorize, as appropriate, new projects and new opportunities for collaboration and the potential need for budget coordination;
3) Identify and discuss policy and programmatic concerns; and
4) Develop plans of actions and/or studies to develop solutions to issues.

5.2. The NNPCC shall be co-chaired by the NASA Associate Administrator for the Office of Earth Science and the NOAA Assistant Administrator for Satellite and Information Services. The co-chairs shall alternately host the meetings of the NNPCC.

5.3. The NNPCC chairs shall each designate an Executive Coordinator for their respective agencies. The Executive Coordinators shall:

1) Prepare an annual summary of joint activities;
2) Plan NNPCC meetings and prepare the minutes of NNPCC proceedings;
3) Notify program, project, and acquisition management personnel to ensure appropriate participation and allow adequate time for them to prepare the necessary information for presentation and review;
4) Collect organizational and programmatic information, descriptions and points of contact for working groups, project teams, advisory organizations, scientific boards, symposia/conferences, strategic

planning exercises, and upcoming Announcements of Opportunities and Research Announcements; and

5) Update Annex I of this Agreement as new project-specific agreements are concluded and present the revised Annex at the next meeting of the NNPCC.

5.4. Both agencies will work within their respective organizations to ensure that the NNPCC appropriately reflects the progress that is being made to conduct present NOAA-NASA activities, as well as to identify and evaluate new collaborative endeavors.

Article 6

EXTERNAL RELATIONS AND RELEASE OF PUBLIC INFORMATION

Each agency shall conduct its own external relations for its agency-specific activities, but shall coordinate external relations for collaborative projects. The term "external relations" refers to interagency and international relations as well as public and media relations.

Article 7

INTELLECTUAL PROPERTY

7.1 Rights In Data. It is the intent of the parties that the information and data exchanged in furtherance of the activities under this Agreement will be exchanged without use and disclosure restrictions unless required by national security regulations or otherwise agreed to by the parties for specifically identified information or data.

7.2 Patent and Invention Rights: Unless otherwise agreed by the parties, custody and administration of inventions made as a consequence of, or in direct relation to the performance of activities under this Agreement will remain with the respective inventing party. In the event an invention is made jointly by employees of the parties or an employee of a party's contractor, the parties will consult and agree as to future actions toward establishment of patent protection for the invention.

Article 8

DURATION AND AMENDMENT OF AGREEMENT

8.1. This Agreement shall enter into force upon signature of both of the parties and shall remain in force indefinitely.

8.2 This Agreement will be reviewed formally at the request of either agency. The Agreement may be amended or terminated by written agreement of the parties. Either party may unilaterally terminate this Agreement upon sixty days notice to the other party.

Article 9

RESOLUTION OF ISSUES CONCERNING AGREEMENT

9.1. Nothing herein is intended to conflict with current NOAA or NASA directives. At the first opportunity for review of the Agreement, all necessary changes will be accomplished by either an amendment to this Agreement or by entering into a new Agreement, whichever is deemed expedient to the interest of both parties. If the terms of this Agreement are inconsistent with existing directives of either of the agencies entering into this Agreement, then those portions of this Agreement which are determined to be inconsistent shall be invalid; but the remaining terms and conditions not affected by the inconsistency shall remain in full force and effect.

9.2 Should disagreement arise on the interpretation of the provisions of this Agreement, or amendments and/or revisions thereto, that cannot be resolved at the operating level, the area(s) of disagreement shall be stated in writing by each party and presented to the other party for consideration. If agreement on interpretation is not reached within thirty days, the parties shall forward the written presentation of the disagreement to respective higher officials for appropriate resolution.

Daniel S Goldin

THE ADMINISTRATOR
OF THE NATIONAL AERONAUTICS
AND SPACE ADMINISTRATION

DATE: 6-11-98

D James Baker

UNDER SECRETARY FOR
OCEANS AND ATMOSPHERE
THE DEPARTMENT OF
COMMERCE

DATE:

ANNEX 1
TO BASIC AGREEMENT BETWEEN NASA AND DOC CONCERNING
COLLABORATIVE ENVIRONMENTAL SATELLITE-RELATED PROGRAMS

Pursuant to Article 4.3.3 of the Basic Agreement:

- Memorandum of Understanding between the National Aeronautics and Space Administration and the National Oceanic and Atmospheric Administration for Earth Observations Remotely Sensed Data Processing, Distributions, Archiving, and Related Science Support, signed July 27, 1989;

- Memorandum of Understanding between the Space Agency of Canada and National Aeronautics and Space Administration and National Oceanic and Atmospheric Administration of the Department of Commerce of the United States of America. Concerning the RADARSAT Project, signed February 27, 1991;

- Memorandum of Understanding among the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce, the United States Coast Guard, the United States Air Force, and the National Aeronautics and Space Administration Regarding U.S. Responsibilities Relating to the U.S. COSPAS-SARSAT System signed October 21, 1991;

- Memorandum of Agreement between the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce and the National Aeronautics and Space Administration Regarding Support by U.S. Ground Stations for the Advanced Earth Observing Satellite (ADEOS) Mission signed June 21, 1994;

- Management Plan for the Landsat Program, signed August 23, 1994;

- Memorandum of Agreement between the Department of Commerce, Department of Defense, and National Aeronautics and Space Administration for the National Polar-orbiting Operational Environmental Satellite System (NPOESS), signed May, 1995;

- Addendum 3 to the NASA/NOAA Memorandum of Understanding to Augment Synthetic Aperture Radar Processing at the Alaska SAR Facility in Support of Near-Real Time U.S. Government Remote Sensing Applications signed August 1995;

- National Oceanic and Atmospheric Administration of the U.S. Department of Commerce and the National Aeronautics and Space Administration Technology Transfer Guidelines for the Initial Joint Polar-Orbiting Operational Satellite (IJPS) System signed October 25, 1995;

- Memorandum of Understanding between the National Space Development Agency of Japan and the National Aeronautics and Space Administration and the National Oceanic and Space Administration of the Department of Commerce of the United States of America for Cooperation in the Advanced Earth Observing Satellite (ADEOS-II) Program signed March 31, 1997;

- Technical Implementation Agreement between the National Oceanic and Atmospheric Administration and the National Aeronautics and Space Administration regarding support by the U.S. Ground System for the Second Advanced Earth Observation (ADEOS-2) Mission of the National Space Development Agency of Japan signed September 8, 1997;

- Memorandum Of Agreement between the National Aeronautics and Space Administration and the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce for Cooperation in the Polar-Orbiting Operational Environmental Satellite Program (POES) signed April 17, 1998; and,

- Memorandum Of Agreement between the National Aeronautics and Space Administration and the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce for Cooperation in the Geostationary Operational Environmental Satellite Program (GOES) signed April 17, 1998.

INITIAL IMPLEMENTATION AGREEMENT

BETWEEN

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

OFFICE OF EARTH SCIENCE

AND

THE NATIONAL POLAR-ORBITING OPERATIONAL ENVIRONMENTAL

SATELLITE SYSTEM INTEGRATED PROGRAM OFFICE

FOR THE

NATIONAL POLAR-ORBITING OPERATIONAL ENVIRONMENTAL SATELLITE SYSTEM PREPARTORY PROJECT

I. PURPOSE.

The Office of Earth Science of the National Aeronautics and Space Administration (NASA) and the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Integrated Program Office (IPO) hereby agree to enter into a partnership to jointly formulate a mission called the NPOESS Preparatory Project (NPP) to accomplish the following objectives:

1. Demonstrate and validate global imaging and sounding instruments, algorithms and pre-operational ground systems prior to the first NPOESS flight.

2. Provide continuity of the calibrated, validated and geo-located EOS Terra and PM-1 systematic global imaging and sounding observations for NASA Earth Science research.

As a minimum, NPP should provide atmospheric sounding and earth surface imaging measurements which meet the Earth Science Enterprise science needs and the IPO NPOESS requirements. It should launch in late-2005 with a mean mission duration in orbit of at least 5 years. The instruments flown on this mission will also be flown and operated on the NPOESS and/or METOP spacecraft flown by the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT).

This Initial Implementation Agreement (IIA) identifies the respective partners responsibilities to be used for the formulation phase of the mission. This is in accord with the policy and procedures set forth in Appendix 1 of the Memorandum of Agreement Between the Department of Commerce, Department of Defense, National Aeronautics and Space Administration For The National Polar-orbiting Operational Environmental Satellite System, dated May 26, 1995.

II. RESPONSIBILITIES

The IPO and the NASA Office of Earth Science shall jointly manage the program and assume the following division of responsibilities:

IPO:

1. Manage and fund the development and procurement of the Cross-Track Infrared Sounder (CrIS) and associated NPOESS related algorithms consistent with the terms and conditions in the IIA between NASA and IPO for an Advanced Technology Microwave Sounder signed August 27, 1998.

2. Manage and fund the development and procurement of the Visible - Infrared Imager Radiometer Suite (VIIRS) and associated NPOESS related algorithms to meet agreed upon NPOESS/NASA requirements.

3. Provide mission flight operation following the formal hand-over by NASA at the conclusion of the post-launch on-orbit checkout.

4. Provide the following ground system capabilities:
   - Stored mission data receive ground stations
   - Primary and backup telemetry and command via National Oceanic and Atmospheric Administration (NOAA) Command and Data Acquisition (CDA) facilities, Air Force Satellite Control Network
   - Network services for data return to Continental United States (CONUS)
   - Prototype operational data processing
   - Prototype operational calibration and validation
   - Ground system integration

NASA:

1. Perform mission systems engineering, integration and testing.

2. Manage and fund the development and procurement of the spacecraft bus.

3. Manage and fund the development and procurement of the Advanced Technology Microwave Sounder (ATMS), consistent with the terms and conditions in the IIA between NASA and IPO for an Advanced Technology Microwave Sounder signed August 27, 1998.

4. Manage and fund the procurement of the launch vehicle.

5. Prepare for, conduct, and oversee launch and post-launch on-orbit checkout.

6. Provide the following ground system capabilities:
   - Rate buffer subsystem for ground stations
   - Backup telemetry and command via Tracking and Data Relay Satellite (TDRSS)
   - Make available to the IPO and/or NOAA any science processing/re-processing capability developed by NASA for NPP.

7. Provide engineering support for anomaly resolution for the life of the mission.

NASA and NPOESS IPO will jointly assume system program management responsibilities and develop integrated performance milestones to be achieved for the formulation, implementation, and operation of the mission and a transition plan to migrate the instruments to future operational NPOESS platforms. Changes involving schedules, costs, or system performance will be promptly communicated as necessary between NASA and IPO.

NASA and NPOESS IPO will jointly participate with NOAA in science level calibration/validation activities for NPP.

Responsibility for data archiving and distribution of data acquired from the NPP spacecraft will be negotiated between NASA and IPO, and/or their respective sponsoring organizations.

Community specific data handling will be the responsibility of the respective organizations.

Periodic mission status reports will be provided to NASA and IPO management.

Each party shall share cost, schedule, and mission justification information with the other in the appropriation process and shall reconsider this agreement should conditions merit.

III. FUNDING.

There shall be no exchange of funds between NASA and IPO. All activities pursuant to this IIA are subject to the availability of appropriated funds, and no provision herein shall be interpreted to require obligation or payment of funds in violation of the Anti-Deficiency Act, 31 U.S.C. § 1341. This IIA is not a funding document, and does not represent the obligation or transfer of funds.

IV. EFFECTIVE DATE

This IIA shall be effective upon the date of the last signature below. It is the intention of the parties to enter into a Final Implementation Agreement at the end of mission formulation and prior to the beginning of implementation (Phase C/D) activity. The formulation phase is expected to be complete in FY 2001.

Ghassem Asrar
Associate Administrator
for Earth Science

20 August 1999
Date:

Gregory Withee
Assistant Administrator
for Satellite and Information Services

26 August 1999
Date:

Richard McCormick
Deputy Assistant Secretary
for Space Plans and Policy

21 November 1999
Date

FINAL IMPLEMENTATION AGREEMENT

BETWEEN

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

OFFICE OF EARTH SCIENCE

AND

THE NATIONAL POLAR-ORBITING OPERATIONAL ENVIRONMENTAL

SATELLITE SYSTEM INTEGRATED PROGRAM OFFICE

FOR AN

ATMOSPHERIC TEMPERATURE AND HUMIDITY SOUNDING SYSTEM

I. PURPOSE

The Office of Earth Science of the National Aeronautics and Space Administration (NASA) and the National Polar-orbiting Operational Environmental Satellite System Integrated Program Office (NPOESS IPO) hereby agree to enter into a partnership to develop and deploy an atmospheric temperature and humidity sounding system which meets both NPOESS operational requirements and NASA scientific requirements for obtaining atmospheric temperature and moisture profiles. This sounding system includes an infrared sounder and a microwave sounder.

The first flight of the sounding system is planned for the NPOESS Preparatory Project (NPP). NPP is a joint mission of the NASA Earth Science Enterprise and the NPOESS IPO that has been authorized for formulation studies. Subsequent flights of the sounding system will be on NPOESS and possibly the European Meteorological Operational (MetOp) spacecraft.

This Final Implementation Agreement (FIA) fulfills the conditions stipulated in the Initial Implementation Agreement (IIA) dated August 27, 1998 and is undertaken pursuant to Appendix 1 of the "Memorandum of Agreement" between the Department of Commerce, the Department of Defense, and the National Aeronautics and Space Administration for the National Polar-Orbiting Operational Environmental Satellite System, dated May 26, 1995.

II. RESPONSIBILITIES

The NASA and the NPOESS IPO agree to jointly undertake the following responsibilities:

1. The NPOESS IPO is developing the infrared component of this system, known as the Cross-Track Infrared Sounder (CrIS), and will provide all flight models. NASA will conduct the procurement and oversee the development and production of the microwave component, to be known as the Advanced Technology Microwave Sounder (ATMS), through the delivery of the first flight model. NASA will provide the funding through the delivery of the first flight model; recurring costs for subsequent flight models of the ATMS will be borne by the NPOESS IPO.

2. NASA and NPOESS IPO have jointly agreed on ATMS performance parameters that are consistent with operational and scientific requirements, performance milestones to be achieved in the course of first unit development, procurement procedures, and contract terms and conditions for the first and subsequent flight models. These joint requirements are documented in the Performance and Operations Specification (POS) for ATMS, which has been reviewed and approved by both the NPOESS IPO and NASA.

3. NASA administration of the ATMS development contract will terminate on a mutually agreed to date, but no earlier than delivery of the first flight unit. The administration of the ATMS contract for procurement of all subsequent flight units will be the responsibility of the IPO and/or its designated NPOESS prime contractor. The NPOESS IPO assumes the responsibility for funding and producing all the subsequent instruments, with NASA retaining full insight into the procurement process. Design or manufacturing changes, which affect performance parameters, will be agreed upon in advance of contract modification by both partners.

4. Likewise, NASA will continue to have appropriate insight into the evolution of the CrIS to ensure that its performance meets joint operational and scientific sounding requirements. Design or manufacturing changes which affect performance parameters will similarly be agreed to by both partners.

The NPOESS IPO will have full responsibility for integrating the ATMS into the NPOESS spacecraft, coordinating the deployment and integration of the instrument on the European MetOp spacecraft (if applicable) and for supplying data from the infrared and microwave atmospheric sounder system to NASA.

III. FUNDING.

All activities pursuant to this FIA are subject to the availability of appropriated funds, and no provision herein shall be interpreted to require obligation or payment of funds in violation of the Anti-Deficiency Act, 31 U.S.C. § 1341. This FIA is not a funding document, and does not represent the obligation or transfer of funds.

Each party shall support the other in the appropriation process and shall reconsider this agreement should conditions merit.

IV. EFFECTIVE DATE

This FIA shall be effective upon the date of the last signature below.

Ghassem Asrar
Associate Administrator
for Earth Science Office

2 August 2000
Date:

John Cunningham
Director,
NPOESS Integrated Program Office

18 July 2000
Date:

Christopher Scolese
Associate Director of Flight Projects
for EOS-G, GSFC

7/27/00
Date:

INITIAL IMPLEMENTATION AGREEMENT

BETWEEN

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

OFFICE OF EARTH SCIENCE

AND

THE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

NATIONAL ENVIRONMENTAL SATELLITE,
DATA, AND INFORMATION SERVICE

TO OBTAIN

GLOBAL TROPOSPHERIC WIND SOUNDER DATA

I. PURPOSE

The Office of Earth Science of the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA) s National Environmental Satellite, Data, and Information Service (NESDIS) (hereafter, NASA and NOAA respectively who are the parties to this agreement) hereby agree to enter into a collaborative project to engage a responsive and verifiable commercial provider of research and operational quality global tropospheric wind sounder data.

This activity has the following objectives:

A. Improve knowledge and understanding of such issues as:

1. Tropical dynamics, including El Nino/Southern Oscillations (ENSO) events, and moisture transport in global water cycle;
2. Dynamics and mechanics of hurricane formation, growth and propagation;
3. Dynamics and role of jets in diagnosing and predicting mid-latitude systems;
4. Role of atmospheric boundary layer in global processes;
5. Transport of trace species, aerosols, and pollution; and
6. Stratospheric/tropospheric interaction

B. Provide global wind observations to improve NOAA operational numerical weather and short-term climate prediction.

The wind sounder data should meet a minimal set of threshold requirements for both NASA/NOAA research missions and NOAA operational mission utility.

II. APPROACH

NASA and NOAA will jointly investigate options for selecting a commercial capability for obtaining these data that will result in the best value to the government. An operational prototype phase is envisioned as a vehicle to fill gaps in technology, demonstrate responsiveness and verifiability of data products, and retire risks in a manner to foster investor interest in financing fully commercial systems. This phase will look to capitalize on the respective agency charters for infusing technology into the commercial sector in order to foster emergence of a new commercial remote sensing capability. If technically and programmatically feasible, implementation could begin as early as FY 2001 for launch in FY 2004.

Within the scope of this agreement, the major options which define the operational prototype path will include one or more elements of:

A. Immediate Commercial Data Buy
B. Government Build and Operate
C. Industry - Government Partnership

This Initial Implementation Agreement (IIA) identifies the respective partners responsibilities for the formulation of activities leading up to a final decision for acquiring the data (hereafter, formulation activities). If warranted, a Final Implementation Agreement (FIA) will be developed to continue this partnership during the implementation phase.

III. <u>AUTHORITIES</u>

A. The Authorities to enter into this IIA are included in the "Basic Agreement Between the National Aeronautics and Space Administration and the U.S. Department of Commerce Concerning Collaborative Programs" signed June 17, 1998, (hereafter, the Basic Agreement).

B. The activities of this IIA will be conducted in a manner consistent with the Basic Agreement. This IIA will be listed in Annex 1 to the Basic Agreement.

IV. <u>RESPONSIBILITIES</u>

The Parties will jointly manage formulation activities and will assume the following division of responsibilities:

A. NOAA will:

1. Define requirement goals and minimum thresholds to meet operational mission requirements, and participate with NASA in defining research requirements;

2. Identify and define a Verification and Validation Plan for operational data;

3. Define, complete and assess the Observing System Simulation Experiments (OSSE) to determine the impact of global tropospheric wind profile data on National Weather Service numerical weather predictions; and

4. Monitor a ground-based lidar winds demonstration and scale its results to a space-based mission.

B. NASA will:

1. Define requirement goals and minimum thresholds to meet science requirements;

2. Identify and define a Verification and Validation Plan for research data;

3. Participate with NOAA in OSSE assessment;

4. Engage its mission design resources to assist NOAA in monitoring a ground-based lidar winds demonstration and scaling its results to a space-based mission;

5. Engage its mission design resources to define an end-to-end mission reference architecture to support a basis of cost for federal acquisition regulations; and

6. Engage its commercial remote sensing expertise to assess non-NASA/NOAA opportunities for the application of winds data and investigate ways to engage the broader commercial sector.

C. NASA and NOAA will jointly:

1. Define a decision process and schedule for evaluation of the technical and programmatic risks for each of the major options. This decision process will result in a final recommendation for obtaining winds data that provides the best value to the Government;

2. Develop a budget-forecasting and financial risk-management algorithm accommodating Federal Acquisition Regulation (FAR) constraints for projects wherein:

a. solicitations are for performance based contracts (PBC s) having focused data specifications as the primary performance criteria;

b. government-industry partnerships for operational prototypes are inclusive as pathfinders to a fully commercial data source; and

c. the Government is the major/controlling customer;

3. Support development, release, and evaluation of any procurement action forthcoming;

4. Provide a final presentation and periodic status reports to both NASA and NOAA management;

5. Share cost, schedule, and mission justification information with the other in the appropriation process and reconsider this IIA should conditions merit; and

6. If and when appropriate, develop a Final Implementation Agreement to continue these activities into the Implementation Phase.

V. FUNDING

Under this IIA, there shall be no exchange of funds between NASA and NOAA. All activities pursuant to this IIA are subject to the availability of appropriated funds, and no provision herein shall be interpreted to require obligation or payment of funds in violation of the Anti-Deficiency Act, 31 U.S.C./1341. This IIA is not a funding document, and does not represent the obligation or transfer of funds.

VI. DURATION

A. This IIA shall be effective upon the date of the last signature below. NASA and NOAA intend to enter into a Final Implementation Agreement (FIA) pursuant to final recommendations, terms and conditions at the completion of formulation activities.

B. This IIA will be reviewed formally at the request of either party. The IIA may be amended or terminated by written agreement of the parties. Either party may unilaterally terminate this IIA upon sixty days written notice to the other party.

C. This IIA will be suspended if the FIA is signed, or will terminate on July 1, 2001.

VII. RESOLUTION OF ISSUES CONCERNING THE AGREEMENT

Should disagreement arise on the interpretation of the provisions of this Agreement, or amendments and/or revisions thereto, that cannot be resolved at the operating level, the area(s) of disagreement shall be stated in writing by each party and presented to the other party for consideration. If agreement on interpretation is not reached within thirty days, the parties shall forward the written presentation of the disagreement to respective higher officials for appropriate resolution.

____

Gregory W. Withee
NOAA Assistant Administrator

for Satellite and Information Services

____
Date:

Formulation Authorization

GLOBAL TROPOSPHERIC WIND SOUNDER(GTWS)

TO: THE GSFC LEAD CENTER DIRECTOR

Earth Science Enterprise Associate Administrator — Date

FORMULATION AUTHORIZATION
GLOBAL TROPOSPHERIC WIND SOUNDER MEASUREMENT
(GTWS)

MEMORANDUM OF AGREEMENT

BETWEEN

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION,

THE DEPARTMENT OF THE NAVY,

AND

THE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

FOR

THE NASA NEW MILLENNIUM PROGRAM EARTH OBSERVING 3 GEOSYNCHRONOUS IMAGING FOURIER TRANSFORM SPECTROMETER /NAVY INDIAN OCEAN METOC IMAGER MISSION

FOR THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION:

Date: 11 July 2002

Dr. Ghassem R. Asrar
Associate Administrator for Earth Science

FOR THE DEPARTMENT OF THE NAVY:

Date: 22 July 02

RADM Richard D. West, N096
Oceanographer of the Navy

Date: 22 JUL 02

VADM Dennis V. McGinn, N7,
Deputy Chief of Naval Operations
Resources, Warfare Requirements & Assessments

FOR THE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION:

Date: 11 July 2002

Mr. Gregory W. Withee
Assistant Administrator for Satellite
and Information Services

MEMORANDUM OF AGREEMENT

1. PURPOSE

The purpose of this Memorandum of Agreement (MOA) between the National Aeronautics and Space Administration (NASA), the Department of the Navy (the Navy), and the National Oceanic and Atmospheric Administration (NOAA) in the Department of Commerce (referred to herein as the Parties) is to establish a framework for cooperation on a mission involving: the development, integration, and launching, of a satellite platform for geosynchronous imaging spectrometer technology; the conduct of space flight operations required for utilization of the technology; and the analysis, calibration/validation, distribution, and technology transfer of the resulting data to meet NASA, Navy and NOAA requirements.

2. BACKGROUND

NASA's New Millennium Program (NMP) objective is to validate revolutionary technologies and innovative measurement concepts that will enable future science measurements. The NASA NMP Earth Observing 3 (EO-3) Project is a Conterminous United States (CONUS) technology demonstration and space flight validation experiment of the Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS) sensor. The GIFTS sensor will provide measurement of water vapor distribution as a function of altitude, leading to determination of tropospheric wind parameters. In addition, the GIFTS sensor will validate the key enabling technologies leading to improved weather and climate analysis and prediction capabilities.

The Navy's Indian Ocean Meteorological and Oceanographic (METOC) Imager (IOMI) Program is the sensor program identified in the Future Year Defense Plan (FYDP) to meet the Navy's Indian Ocean METOC requirement as defined by the Oceanographer of the Navy. The IOMI Program objective is to develop, integrate, and launch an advanced technology sensor providing a demonstration of operational utility of high-resolution weather imagery direct to Navy ships in the Indian Ocean. The NASA EO-3 GIFTS mission, with design enhancements to extend the sensor and mission lifetime and orbit re-location, will meet the Navy requirements.

NOAA's objective is to confirm GIFTS technology can meet requirements for future operational geosynchronous sounders and provide for early development of processing algorithms that can shorten the time between launch and operations for future NOAA operational sounders.

This joint program provides the opportunity for direct infusion of these technologies into the NOAA advanced geosynchronous sounder program and into future military and civil weather systems.

For these reasons, the Parties have agreed to collaborate on a joint EO-3 GIFTS-IOMI Mission. The overall mission lifetime design requirement is seven years. This mission envisions two distinct phases:

Phase 1 (the CONUS Phase) will be the NASA GIFTS New Millennium Program technology demonstration phase carried out over the CONUS. This phase has a planned duration of 12 months not to exceed 16 months unless agreed upon by the Navy. While NASA and the Navy operate the EO-3 GIFTS-IOMI satellite over the CONUS for the first 12-16 months, NOAA will capture and analyze GIFTS data to enable the GIFTS measurement concept to achieve a successful transition from research to operation.

Phase 2 (the Indian Ocean Phase) will be a Navy demonstration of operational utility over the Indian Ocean, with a planned duration of at least five years. By demonstrating this capability over the Indian Ocean, the Navy mission will provide valuable data to fill a large weather data void, which in turn has the potential to provide great improvements in global weather forecasting.

GIFTS is the primary payload for the CONUS mission. Additional payloads (instruments) are secondary payloads and cannot interfere with the development, deployment or CONUS utilization of the GIFTS sensor.

3. AUTHORITY

NASA, the Navy and NOAA are authorized to enter into this MOA pursuant to Sections 203(c)(5) and (6) of the National Aeronautics and Space Act of 1958, 42 U.S.C. § 2473(c)(5) and (6), and Section 3 of the Weather Service Organic Act, as amended, 15 U.S.C. § 313.

4. SPECIFIC RESPONSIBILITIES

The Parties agree to provide their best efforts to meet the responsibilities stipulated below.

4.1. NASA will use its best efforts to:

a) Provide funding per Section 6 of this MOA.
b) Develop the protoflight GIFTS sensor in accordance with NMP EO-3 and applicable IOMI requirements consistent with cost and schedule.
c) Manage the development of the EO-3 GIFTS-IOMI Mission, including the scheduling, programmatic and technical interchange/review meetings with the Navy and NOAA, to facilitate EO-3 GIFTS-IOMI Mission development.
d) Jointly with the Navy and NOAA, through the Interagency Coordinating Office (ICO), coordinate, direct and manage the merging of mission, programmatic and technical requirements and the implementation of those requirements for the integrated mission as defined in Sections 7.2 – 7.4 below.

e) In partnership with the Navy, identify, negotiate and enter into additional agreements for secondary payloads.

f) Validate GIFTS technologies and the GIFTS measurement concept based on measurements made during the CONUS Phase.

g) Operate the GIFTS/IOMI mission/spacecraft during the CONUS Phase. Develop all facilities and procedures for operation to ensure safe and efficient transfer of control to the Navy at the end of the CONUS Phase, including:

- Support fleet demonstrations and calibration/validation of selected Navy products before Indian Ocean demonstration of Navy operational utility
- Provide sensor operations training for Navy and/or designated contractor personnel before on-orbit delivery of the GIFTS sensor

h) At the completion of the CONUS Phase of the mission, carry out a smooth transfer of operational responsibility from NASA to the Navy, including:

- Delivery to the Navy all Ground Support Equipment (GSE) specific to the EO-3 GIFTS-IOMI Mission required for routine operation of the sensor including GSE hardware, software, and documentation related to the command and control of the sensor in flight .
- Delivery to the Navy of a copy of all GIFTS sensor documentation including as-built drawings, as-built source code, operations plans, operations manuals, and calibration and validation data and results.

i) Develop plans and proposals and identify funding for potential science use of the EO-3 GIFTS-IOMI satellite during the Indian Ocean Phase, as appropriate, and support the negotiation of related agreements for potential scientific Indian Ocean mission operations, as mutually agreed by the Parties.

j) Assist the Navy and NOAA in obtaining continued program support.

4.2. The Navy will use its best efforts to:

a) Provide funding per Section 6 of this MOA.

b) Participate in the EO-3 GIFTS-IOMI mission development through contribution of management and key personnel, scheduling, programmatic and technical interchange/review meetings with NASA and NOAA.

c) Jointly with NASA and NOAA, through the Interagency Coordinating Office (ICO), coordinate, direct and manage the merging of mission, programmatic and technical requirements and the implementation of those requirements for the integrated mission as defined in Sections 7.2 – 7.4 below.

d) In partnership with NASA, identify, negotiate and enter into additional agreements for secondary payloads.

e) Provide for an increase in the reliability of the GIFTS instrument beyond the requirement for the CONUS Phase to meet the mission lifetime requirement of seven years.

f) Provide the acquisition vehicle for the spacecraft for the EO-3 GIFTS-IOMI Mission (including its design, integration and testing).

g) Provide the launch vehicle and launch services for the GIFTS-IOMI mission and selected secondary payloads to achieve geosynchronous transfer orbit through a Memorandum of Agreement with the Department of Defense (DoD) Space Test Program (STP), as mutually agreed between NASA, the Navy and NOAA.

h) Support mission/spacecraft operations during the CONUS Phase, as required to meet Navy mission requirements during Phase 1. Accept the spacecraft on-orbit at the end of the CONUS Phase, transfer orbit location to the Indian Ocean, and assure ground system operations for the Indian Ocean Phase

i) File for and provide orbital slots and RF frequency allocations for Phase 1 and Phase 2 mission.

k) Provide appropriate end of life disposal for the EO-3 GIFTS-IOMI satellite.

l) Review, and accommodate if feasible, NASA and NOAA proposals for scientific and weather service use of the EO-3 GIFTS-IOMI satellite during the Indian Ocean Phase. Support the negotiation of related agreements for scientific and weather service Indian Ocean Phase mission operations, as mutually agreed by the Parties.

m) Assist NASA and NOAA in obtaining continued program support.

4.3 NOAA will use its best efforts to:

a) Provide funding for NOAA commitments per Section 6 of this MOA .

b) Jointly with the Navy and NASA, through the Interagency Coordinating Office (ICO), coordinate, direct and manage the merging of mission, programmatic and technical requirements and the implementation of those requirements for the integrated mission as defined in Sections 7.2 – 7.4 below.

c) Provide downlink reception and associated data ground system operations (including GIFTS operational algorithms, software and data archiving) starting immediately after completion of launch and on-orbit delivery and continuing through completion of the CONUS Phase. Effect transfer of ground station operations to Navy at CONUS on-orbit transfer of the spacecraft to Navy.

d) Provide timely access to all available raw data and data products produced as part of the GIFTS technology and measurement concept validation to NASA for NMP technology validation, and to the Navy to facilitate Navy Indian Ocean mission operations.

e) During the CONUS Phase, collect and distribute the data necessary to maximize the use of GIFTS data, and support research efforts ensuring the readiness of operational product processing for the launch of the advanced geosynchronous sounder. In addition, cooperate with NASA to designate tasking to collect this data during the CONUS Phase.

f) Perform applied research aimed at developing algorithms for using GIFTS data and establishing a stable set of products and nowcasting tools ready for use when the advanced geosynchronous sounder data are available.

g) Make full use of the NASA/NOAA Joint Center for Satellite Data Assimilation to develop efficient assimilation mechanisms and to perform model benefit studies to demonstrate the advantages of an interferometer sounder to Numerical Weather Prediction.

h) Integrate GIFTS technology into NOAA's operational advanced geosynchronous sounder, as appropriate (utilizing the NASA GOES Project office). NOAA will establish a time and material account to cover partnership costs in support of this requirement.

i) Participate in scheduling, programmatic and technical interchange/review meetings with NASA and the Navy to facilitate EO-3 GIFTS-IOMI Mission development.

j) Develop plans and proposals and identify funding for National Weather Service (NWS) use of the EO-3 GIFTS-IOMI satellite during the Indian Ocean Phase, as appropriate. Also, support the negotiation of related agreements for scientific Indian Ocean Phase mission operations, as mutually agreed by the Parties.

k) Assist NASA and Navy in obtaining continued program support.

l) Manage these activities and deliver products to the EO-3 GIFTS-IOMI Program, as appropriate, together with the time and material support in item 4.3(f).

5. MAJOR MISSION MILESTONES

The key milestones shown below are included to convey the intent of NASA, the Navy and NOAA to develop, launch and operate the EO-3 GIFTS-IOMI Missions. The target launch date for EO-3 GIFTS-IOMI satellite is November 2005, with the target relocation date of the flight system to the Indian Ocean between November 2006 and March 2007. The schedule for these events is critical to the timeliness of both the NASA NMP technology validation and the Navy Indian Ocean operational utility demonstration.

TASK	COMPLETION
a) GIFTS-IOMI System Requirements Identified	Jul 2000
b) GIFTS-IOMI Preliminary Design Completed	Mar 2001
c) GIFTS-IOMI Mission Confirmation	May 2002
d) GIFTS-IOMI Mission CDR	Mar 2003
e) Ground System Availability	Oct 2004
f) Spacecraft Bus Delivery to System Integration and Test	Jan 2005
g) Payload(s) Delivery to System Integration and Test	Mar 2005
h) Mission Launch Readiness Date	Nov 2005
i) Phase 1 Completion of EO-3 Calibration/Validation of Data/Technology Demonstration	Launch+14 months
j) Phase 2 Relocation of Satellite to Navy Indian Ocean Mission	Launch+16 months
k) Completion of Indian Ocean Phase 2	Launch+76 months

6. ANTICIPATED PROGRAM FUNDING ($M)

	Prior	FY02	FY03	FY04	FY05	FY06	FY07	TOTAL
NASA*	26.80	27.20	18.30	10.00	3.00	3.00	1.60	89.90
Navy*	0.50	6.75	12.72	15.29	5.28	16.31	8.90	65.75
NOAA	0.20	2.00	10.20	10.20	5.20	5.20	5.20	38.20
Total**	27.50	35.95	41.22	35.49	13.48	24.51	15.70	193.85

* Each partner is responsible to provide funding to offset cost growth consistent with that partner's share of responsibility as shown in Section 4. The partners agree to address and resolve funding phasing issues and cost risks in a timely fashion. Funding does not include secondary payloads and associated costs.

**Total reflects funds required for GIFTS sensor design, increased lifetime and development, and ground system costs plus funds to acquire the spacecraft and support mission requirements. To the extent required by DoD Instruction (AFI 10-1202(I), Section 1.13.5), the Navy and NASA shall fund STP for any increases in costs incurred as a result of GIFTS-IOMI mission delays. The cost of the Delta IV and launch service, estimated at $75 million, is in addition to funding outlined in Section 6 above and raises the DoD (Navy, STP) mission contribution to ~$140M, for the total mission cost to ~$268 million, not including the cost of secondary payloads.

Funding outlined reflects the agency contribution to the program, disbursement details will be outlined in the Project Implementation Plan, i.e. sensor development, ground station development, etc.

7. OVERSIGHT AND COORDINATION

7.1. A Senior Oversight Board will set the overall direction of the EO-3 GIFTS-IOMI Mission and will resolve any inter-agency difficulties or disputes not capable of resolution through coordinating functions of the Parties at lower levels. The Senior Oversight Board will be composed of the following senior officials responsible for the three agency programs contributing to the EO-3 GIFTS-IOMI Mission: for NASA, the Associate Administrator for Earth Science; for the Navy, the Deputy Chief of Naval Operations, in coordination with the Oceanographer of the Navy; and for NOAA, the Assistant Administrator for Satellite and Information Services. The members of the Senior Oversight Board may designate a senior official within their respective programs to represent them on the Board.

7.2. Program Offices from the Parties, NASA's NMP Office, the Navy's IOMI Program Office, and NOAA's Office of Systems Development will coordinate their activities to accomplish the agency responsibilities set out in Sections 4, 5, and 6 of this MOA. The three program offices will assure that the EO-3 GIFTS-IOMI Project receives the resources necessary to accomplish the mission. In addition, the program offices will conduct appropriate reviews on the progress of the mission, and will make timely reports to their respective authority.

7.3. An Interagency Coordinating Office (ICO) will be formed including representation from the Parties' Program Offices, and will be chaired by an ICO Director from NASA. The ICO will provide an integrated management approach and structure for mission implementation. The ICO will be responsible for coordinating, directing and managing the merging of mission, programmatic and technical requirements from the Parties, and for managing the implementation of those requirements for the integrated GIFTS-IOMI mission. In addition, the ICO will be responsible on behalf of mission implementation for all organizational interfaces outside Project procurements and similar contractual agreements.

7.4. The Project Office at LaRC will report to the ICO and will be the lead office for the EO-3 GIFTS-IOMI Mission implementation. This office includes the Project Manager (NASA) and Deputy Project Managers (detailed from the Navy and NASA). The GIFTS-IOMI Project Plan will be the Implementation Plan for this agreement. The members of the ICO will have approval authority for the Project Plan.

7.5. Each Federal agency participating in the EO-3 GIFTS-IOMI Mission will be responsible for its own administrative and personnel costs, including the costs of any of its officials detailed to the offices of another agency. Nothing in this MOA shall be interpreted to require the interagency funding of a board, panel or office in violation of the Congressional prohibition contained in Section 610 of the Treasury and General Appropriations Act, 2002 (P.L. 107-67).

8. LIABILITY AND RISK OF LOSS

Each Party agrees to assume liability for its own risks associated with activities undertaken pursuant to this MOA.

9. DATA EXCHANGE

The Parties intend that the information and data produced during mission operations shall be exchanged without use and disclosure restrictions unless required by statute or regulation, or unless otherwise agreed to by the Parties for specifically identified information or data. During the Navy IOMI mission, data may be subject to military embargo restrictions. Any media can be used as appropriate for the type of information. Direct access to a database or tapes shall constitute transfer.

10. AMENDMENT AND TERMINATION.

The Parties will review this MOA annually and amend it as required. This MOA may be amended at any time upon the mutual consent of all three Parties. Amendments must be in writing, and signed by the authorized representatives of each of the three Parties.

This MOA will terminate automatically upon completion of the EO-3 GIFTS-IOMI Mission, or eleven years from the effective date of this MOA, whichever comes first. The Parties may amend this MOA pursuant to the preceding paragraph to extend the termination date. Any Party may terminate its participation in this MOA at its sole discretion, subsequent to providing 120 days advance written notice to the other Parties. In the event of a termination, the Parties agree to negotiate the equitable settlement of termination costs.

11. DISPUTE RESOLUTION

Should any disagreement arise on the interpretation of the provisions of this MOA, or amendments and/or revisions thereto, that cannot be resolved at the operating level, the area or areas of disagreement shall be stated in writing by each of the disputing Parties and presented to the Senior Oversight Board for resolution.

12. AGENCY POLICIES, REGULATIONS AND DIRECTIVES

Nothing in this MOA is intended to conflict with current laws or NASA, Navy, or Department of Commerce policies, regulations, or directives. If the terms of this MOA are inconsistent with existing directives of any of the three agencies, then those portions of this MOA which are determined to be inconsistent shall be invalid; but the remaining terms and conditions not affected by the inconsistency shall remain in full force and effect. At the first opportunity for review of this MOA, all necessary changes will be accomplished by either an amendment to this MOA, or by entering into a new agreement, whichever is deemed expedient to the interest of the Parties.

13. ANTI-DEFICIENCY ACT

All activities under or pursuant to this MOA are subject to the availability of appropriated funds, and no provision herein shall be interpreted to require obligation or provision of funds in violation of the Anti-Deficiency Act, 31 U.S.C. § 1341.

14. EFFECTIVE DATE

This MOA shall be effective on the date of the last signature to this MOA.

Questions submitted by Representative Bart Gordon

Q1. What specific Earth Science-related responsibilities is NASA transferring or planning to transfer to NOAA?

a. What are the timetables for the transfers?

b. What are the estimated budgetary impacts of the responsibilities transferred?

A1a,b. NASA has long served as the research, technology development, and satellite development source for the Nation's civil space-based remote sensing capability and will continue to perform in this capacity. During the past several years, the NASA–NOAA partnership has evolved across a broad front to meet the Nation's need for affordable operational and research observations. (1) techniques; (2) technologies; (3) measurement responsibilities; and (4) remote sensing instruments and platforms. NASA's baseline budget reflects our expectation that the ongoing partnership with NOAA will continue to evolve. However, the budgetary impacts associated with the transfer of responsibilities in not known at this time. Each of these areas involves joint NASA and NOAA efforts that lead to the transfer of innovative capabilities, as summarized below:

Techniques—The focus in this area is on the utilization of remote sensing data to improve the models that NASA and NOAA use to create weather and climate forecasts. NASA, NOAA and USAF have established the Joint Center for Satellite Data Assimilation as a means to accelerate the use of research data to improve operational weather and climate forecasting. NASA has also been working with NOAA's National Hurricane Center to improve hurricane track forecasting via new model algorithms and data.

Technologies—New technologies will focus on the improvement of NOAA's weather forecasting capability based on science and technology through new spacecraft and modeling. The next generation weather satellites will use satellite spacecraft that are based on those developed by NASA and its prime contractor for the EOS Aqua and Aura missions.

Instruments and Platforms—The development of advanced instruments and platforms by NASA in a research context that can be used in NOAA's next generation of operational environmental satellites. The NPOESS VIIRS and ATMS sensors, for example, continue the imaging and sounding observations by the NASA EOS MODIS and AIRS sensors, respectively.

Measurements—New instruments prepare the way for transition of measurement responsibilities. This includes plans, underway since the late 1990s, to continue selected climate measurements begun by NASA's Earth Observing System via transfer of instrument technologies and measurement responsibilities begun by EOS Terra and Aqua to the National Polar-orbiting Operational Environmental Satellite System (NPOESS). The first fruit of this effort will be the NPOESS Preparatory Project, a satellite now in development jointly by NASA and the NPOESS Integrated Program Office. This mission will carry both the VIIRS and ATMS instruments as well as others. Based on the strategy of assuming that a number of the critical measurements made by Terra and Aqua would be done through NPOESS, NASA was able to reduce the planned budget for systematic Earth science measurements.

NASA may propose innovative next generation missions to begin during this time frame, in keeping with the general strategy of transitioning mature measurement responsibilities so that operational systems can benefit and NASA can move on to the next frontier. In parallel, NASA, NOAA and their European counterparts have been working over the last three years on a plan to transition ocean surface altimetry measurements begun by the NASA/CNES TOPEX/Poseidon and Jason missions to a future operational system using the Ocean Surface Topography Mission now under development as a "bridge." Not all measurements begun by EOS are slated for transition to NPOESS, but the significant ones that are, including the basic imaging and sounding done by Terra and Aqua, help in enabling the reduced budget planned for Earth science to still accommodate a mix of continued long-term measurements, and first implementation of new types of global measurements, for example through the Earth System Science Pathfinder line of competed missions and the Global Precipitation Mission.

Opportunities flow in the other direction as well, for example in the area of flight of NASA research instruments on NOAA spacecraft. Currently, attention is focused on future geostationary missions. NASA continues to build and launch Geostationary Operational Environmental Satellites for NOAA, with the recent launch

of GOES–N on May 20, 2005. The next generation series will begin with GOES–R. NASA and NOAA are discussing a strategy to reserve capacity on this series of satellites for demonstration of advanced instruments of importance to both agencies.
Major measurement transitions in work:

- Climate quality atmosphere and biosphere measurements begun by Terra and Aqua to NPOESS (~2010) via NPP (~2006)
- Upper atmosphere ozone measurements from TOMS & Aura to NPOESS (~2010) via NPP (~2006)
- Land cover change measurements from Landsat 7 to NPOESS Operational Land Imager (~2010)
- Ocean surface topography from TOPEX/Poseidon and Jason to an NOAA/EUMETSAT operational system via NASA/CNES development and NOAA/EUMETSAT operation of the Ocean Surface Topography Mission (2008)
- Next generation geostationary satellites beginning with GOES–R (~2012)

Q2. What do you consider the most promising future benefits that the Nation might gain from continued investments in Earth Science research? What will be the negative impacts on society if NASA's commitment to Earth Science research and applications is diminished in the coming years?

A2. NASA's Earth Science programs are our nation's primary innovators in providing new information about the global Earth system using the unique vantage point of space. NASA's perspective is global, and emphasizes the "Earth system view" that encourages understanding of the interconnections between various components of the Earth system (atmosphere, oceans, biosphere, cryosphere, and lithosphere). NASA's commitment to Earth science research and application directly enables advanced understanding of the current interactions and future evolution of the Earth system, as well as allows NASA to support the U.S. Climate Change Science Program (CCSP).

The space-based missions carried out by NASA provide information about the global distribution of Earth system parameters never before available on the spatial and temporal scales that NASA can provide. Recent examples include ice sheet and sea ice changes in polar regions (from ICESat), more accurate measurements of the Earth's gravitational field and their analysis to determine information about water stored underneath the Earth's surface (from GRACE), distribution and nature of aerosol particles that affect climate, precipitation, and air quality (from Terra), and distribution of precipitation over the ocean in the tropics and subtropics (from TRAM). Future space systems will provide significant enhancements in our knowledge of the global three-dimensional distribution of clouds and aerosols, and then high-resolution information about the global distribution of carbon dioxide (suitable for inferring information about global sources and sinks), and ocean salinity.

NASA contributes to the record of long-term satellite measurements needed to help evaluate change in the Earth system and help scientists separate between natural and human-induced changes. Examples include studies of ozone distributions (from the TOMS series), solar irradiance (most recently from UARS, ACRIMSAT, and SORCE), of ocean surface topography (from Topex/Poseidon and Jason), and of the Earth's overall radiation budget (most recently from the CERES instruments aboard the Terra and Aqua spacecraft). The long-term need for precise and accurate calibration is not something that has been available from operational platforms in the past. NASA's efforts also include a significant focus on modeling and data assimilation to be sure that new data can be understood and used to test hypotheses of our current understanding of the Earth system's behavior and to improve our capability to predict it in the future.

NASA strives to facilitate the use of its data in supporting policy development and resource management through its applied science program, partnering with other federal agencies to accelerate the process by which space-based data can be used to serve society (e.g., improve weather and climate forecasting and prediction of natural hazards). NASA's technology program constitutes an investment in future Earth science, developing the observational tools and techniques that will enable new views of the Earth in the future, making possible measurements not currently possible today as we look to push back the frontiers in Earth remote sensing (e.g., more frequent temporal sampling, improved determination of the vertical dimension in the measurement of Earth system parameters). A vigorous basic research program underlies all of the above so that as new information is gained, scientists can innovatively incorporate new knowledge into their studies, develop and test hypotheses, improve models, and develop newer techniques that will enable new knowledge in the future.

Q3a. Two years ago, the Space Studies Board of the National Research Council recommended the establishment of an Interagency Transition Office to manage the issues involved in transitioning the capabilities developed in research instruments to the operational systems that support weather monitoring and forecasting.

Have NASA and NOAA taken any steps to establish such an organization? If not, why not?

A3a. NASA and NOAA are actively engaged in establishing the Joint Working Group on Transition Research and Operations (R&O). This joint working group includes senior management from both agencies and a structured approach to involve key personnel for each of the areas for transition. The approach is to establish agreement on specific capabilities to be transitioned and to assign teams with representatives from NASA and NOAA to participate in developing the Capability Implementation Plans.

Q3b. If so, when was the organization established who heads it, and what is its charter?

A3b. An ad hoc Joint Working Group (JWG) was organized and has been holding regular bi-weekly meetings since October 2004. Dr. Colleen Hartman (NOAA) and Dr. Mary Cleave (NASA) are the senior managers responsible for oversight of the ad hoc JWG. Gary Davis (NOAA) and Ron Birk (NASA) are the co-leads for the ad hoc JWG.

The roles and responsibilities include:

- NASA and NOAA designated representatives lead the JWG. The JWG develops, implements, and facilitates a senior level collaboration process. This collaboration process is used to coordinate, evaluate, identify, and transition appropriate NASA research results (capabilities) for NOAA operational and applied research use; and appropriate NOAA operational assets (capabilities) to support NASA research.
- Designated NASA and NOAA senior representatives jointly provide oversight of and accountability for, this working group. These representatives are responsible for coordination of performance measures and goals, and compliance with their respective agency policies and processes relevant to successful implementation and maintenance of a bilateral R&O process.
- An initial transition plan detailing the R&O process, including an initial set of implementation plans for transition of specific research result capabilities, will be submitted to senior NASA and NOAA leadership for approval by September 30, 2005.

Q3c. Does the organization determine how transition costs will be allocated between the two agencies? If not, who does?

A3c. The R&O Transition Plan being formulated by the JWG includes a systematic approach to develop Capability Implementation Plans for each research capability that is identified for transition to operations. The budget associated with transitioning the capability will be included in the Capability Implementation Plan for senior management review. The agencies will determine how transition costs will be allocated based on the approved version of the Capability Implementation Plan.

Q4. Based on correspondence between Admiral Lautenbacher and then-NASA Administrator O'Keefe, it appears that there was no advance coordination between NASA and NOAA when NASA decided to terminate the Tropical Rainfall Monitoring Mission last year.

a. Is that correct?

b. If so, why wasn't there adequate advance coordination?

A4a,b. There has been considerable coordination between NASA and NOAA regarding TRMM, dating back to 2001. NASA and NOAA personnel have discussed TRMM re-entry plans in a number of forums, including workshops, correspondence, and meetings. In April and July 2003, NASA sent letters to the two registered NOAA TRMM real-time data users (John Paquette/NESDIS and Stephen Lord/NCEP) stating NASA's expectation that TRMM's decommissioning could begin as early as the first quarter of 2004. In July 2004, ten days prior to the mailing of the correspondence cited by Rep. Gordon, nine senior NOAA staff members representing a broad cross section of NOAA were notified via e-mail of the imminent decommissioning.

Questions submitted by Representative Mark Udall

Q1. The FY 2006 budget request has combined the Earth Systems and Sun-Earth Connections budgets. Please provide a detailed crosswalk between the FY 2005 budget request and FY 2006 budget request and its five-year runout with the Earth Systems and Sun-Earth Connections budgets broken out separately.

A1. See attached budget crosswalk and five-year run-outs.

Q2. Due to a cut in funding, there are plans to end several extended missions in October of 2005, including Voyager.

Q2a. Will there be a new Senior Review to reconsider the planned terminations?

A2a. Yes, decisions on scientific priorities will be made once NASA receives input from both the Sun-Earth Connection and Earth System Science Senior Review Panels. These panels, composed of external and independent senior researchers with relevant knowledge and experience, meet periodically to review proposals for innovative research, accomplished with existing space assets. The panels assist NASA by evaluating the scientific merit of each extended mission on a "science-per-dollar," basis in terms of the expected returns from new science goals.

Q2b. If so, when will it take place?

A2b. The Earth System Science review is currently in progress and the Sun-Earth Connection review is expected to convene in the fall of 2005.

Q2c. Will funding for these missions be maintained until a new Senior Review is completed? How much funding would be required?

A2c. NASA will permit the Sun-Earth Connection missions to operate while the Senior Review process provides for a new assessment of the future scientific value of these operating missions. This is expected to cost approximately $20.6 million in FY 2006. At the conclusion of the Panels' deliberations, NASA will use their assessments and findings to develop Agency decisions regarding the continued operation of these missions.

Previous Enterprise/Theme Structure
Breakout of Earth-Sun Systems

	FY05	FY06	FY07	FY08	FY09	FY10
Earth Sun Systems	$2,156	$2,064	$2,081	$2,132	$2,359	$2,325
"Previous SEC"	$696	$702	$731	$803	$897	$891
"Previous Earth Science	$1,460	$1,362	$1,350	$1,329	$1,462	$1,434

FY05 Init. Op Plan	FY 2005 - 7 Enterprises, 18 Themes
7,680.9	Science, Aeronautics & Exploration
4,067.8	**SPACE SCIENCE**
1,125.0	Solar System Exploration
681.1	Mars Exploration
52.0	Lunar Exploration
1,135.7	Astronomical Search for Origins
377.5	Structure and Evolution of the Universe
696.4	Sun-Earth Connection
1,459.4	**EARTH SCIENCE**
1,383.6	Earth System Science
75.8	Earth Science Applications
1,030.8	**BIO & PHYSICAL RESEARCH**
481.6	Biological Science Research
295.8	Physical Science Research
253.4	Research Partnerships & Flight Support*
906.2	**AERONAUTICS**
906.2	Aeronautics Technology
216.8	**EDUCATION**
216.8	Education Programs
8,484.2	Exploration Capabilities
1,653.8	**EXPLORATION SYSTEMS**
526.5	Transportation Systems
1,127.2	Human & Robotic Technology
6,830.4	**SPACE FLIGHT**
1,676.3	International Space Station
4,669.0	Space Shuttle
485.1	Space & Flight Support
31.3	Inspector General

FY 2006 - 4 Directorates, 12 Themes	FY05 Init. Op Plan	FY06 Pres Bud
Science, Aeronautics & Exploratic	9,334.7	9,661.0
SCIENCE	5,527.2	5,476.3
Solar System Exploration	1,858.1	1,900.5
The Universe	1,513.2	1,512.2
Earth-Sun System	2,155.8	2,063.6
EXPLORATION SYSTEMS	2,684.5	3,165.4
Constellation Systems	526.0	1,120.1
Exploration Syst Research & Tech	722.8	919.2
Prometheus Nuclear Syst & Tech	431.7	319.6
Human Systems Research & Tech	1,003.9	806.5
AERONAUTICS RESEARCH	906.2	852.3
Aeronautics Technology	906.2	852.3
EDUCATION	216.8	166.9
Education Programs	216.8	166.9
Exploration Capabilities	6,830.4	6,763.0
SPACE OPERATIONS	6,830.4	6,763.0
International Space Station	1,676.3	1,856.7
Space Shuttle	4,669.0	4,530.6
Space & Flight Support	485.1	375.6
Inspector General	31.3	32.4

Budget Authority in $ Millions

* 26.9M of RPFS work in FY05 is moved to ESRT in the FY06 structure.

Questions submitted by Representative Michael M. Honda

Q1. What priority is NASA's Earth Science program as NASA pursues the President's exploration initiative?

Q1a. How have the recent decisions to cancel, de-scope, or delay recent Earth observing missions or mission programs been made? In particular, please explain the rationale for seeking the assistance of the National Academies in determining what the highest priority areas should be and then making changes before the results of that study are known?

A1a. NASA's Guiding National Objectives specifically identify studying the Earth system from space, and developing new space-based and related capabilities for this purpose, as a priority for the Agency. Not only are NASA's activities in Earth Science are essential to the achievement of NASA's mission, they directly support three Presidential initiatives: Climate Change, Global Earth Observation, and Collaborative Oceans Research.

In all of NASA's science disciplines, decisions often must be taken between Decadal Surveys or triennial strategic plans, and are taken based on the best available data on science community priorities and prior strategic plans and surveys. As such, the Science Mission Directorate generally chooses to stay the course on missions already in development, and if necessary, defer missions that were only in the formulation stage, and cancel selected missions where an alternative source of data could be identified.

By applying these criteria to NASA's Earth science missions, only the Glory mission was descoped in the FY 2006 budget to an instrument-only build. The remaining Earth science missions were left largely unchanged, reflecting the need to respond to national priorities in Earth science and in recognition of the fact that the results of the Decadal Survey would not be available until late 2006.

Q1b. What role is full-cost accounting and the fact that it was not accompanied by the appropriate reallocation of salary and other infrastructure money to support those scientists working on critical Earth Science projects playing in these decisions?

A1b. Adoption of full cost accounting practices has neither affected the strategy for pursuit of Earth science by NASA in the era of the Vision for Space Exploration, nor the process of prioritization of research and missions in the Science Mission Directorate. There are important questions to address in this arena, and this is the subject of the National Research Council decadal survey for Earth science now underway. However, these questions exist quite apart from the topic of full cost accounting.

Funds previously carried separately for civil servant salaries and institutional support were added to program budgets (including Earth science) in FY 2005 and beyond. Implementation of full cost accounting and management posed some challenges in the start-up phase, but the magnitude of these problems should decrease over time as we get more experience in working within this new environment. The inherent difficulty in making this significant transition led to some short-term transient effects and some near-term challenges in FY 2005 that affected university researchers, civil servants, and contractors. We anticipate the process of soliciting, selecting, and funding science proposals from the community (in both academia and NASA Centers) in the era of full cost accounting will be smoother in the coming fiscal year.

Questions submitted by Representative Al Green

Q1. Given the increasing vulnerability to extreme weather and climate variations as seen by the tsunami and the various hurricanes that hit Florida, what initiatives, if any, does NASA currently have to explore such events? NASA has been a major sponsor of such research in the past; what initiatives does NASA have planned for the future? What effect will budget constraints have on these projects?

A1. **Tsunami:** A capable tsunami warning system must be both reliable and cost effective. Tsunamis are caused by plate boundary earthquakes, with the most devastating tsunamis occurring within a few hundred miles of the earthquake's epicenter due to both the larger amplitude of the tsunami wave and the lack of sufficient warning. As with all geohazards, significant savings in life and property can result from a tsunami warning system that provides the information necessary for risk assessment, warning, and recovery. NASA's research and technology sponsored primarily by the Earth-Sun Science Division of the Science Mission Directorate seeks to address these fundamental requirements.

NASA is participating within the IWGEO and with other federal and international organizations to insure the effective distribution of these research and development results. Imagery from four NASA spaceborne instruments shed valuable insights into the Indian Ocean tsunami that resulted from the magnitude 9 earthquake southwest of Sumatra on December 26, 2004. These images offered several unique views of portions of the affected region. The data helped scientists and government agencies to assist with disaster recovery and will be used in mitigating the effects of future natural hazards and increasing our understanding of how and why tsunamis strike.

Tropical Cyclones: One of the least understood issues regarding tropical cyclone (TC) behavior are the factors that influence TC genesis and rapid intensification. Hurricane Charley during 2004 is an example of a TC that underwent unpredicted rapid intensification just hours before landfall in northern Florida.

NASA is leading a major field experiment based in Costa Rica during July 2005 called the Tropical Cloud Systems and Processes (TCSP) campaign. The aim of TCSP is to investigate atmospheric and oceanic processes governing the formation and intensification of hurricanes. Costa Rica provides the ideal mission location for accessing a variety of TCs developing across the western Caribbean, Gulf of Mexico and Eastern Pacific. In a manner similar to the highly successful series of NASA CAMEX (Convection and Moisture Experiments) investigations, the NOAA Hurricane Research Division P3–Orion aircraft will fly joint missions with the NASA ER–2 and Aerosonde aircraft during TCSP. The NASA ER–2 is a unique, high-flying platform with a sensitive Doppler radar, passive microwave radiometer and atmospheric profilers that serve as a "virtual satellite" and can thus be positioned to optimally sample critical regions of developing tropical cyclones. One important goal of TCSP is to improve the numerical representation of hurricanes using the specially collected aircraft and satellite observations. For instance, TCSP scientists will work closely with Florida State University (FSU) scientists to identify data sets to optimize the highly successful FSU Super ensemble hurricane forecast prediction tool.

It is anticipated that the TCSP mission will answer many key questions pertaining to the genesis of intense tropical vortices, in addition to raising many other questions. For instance, NASA scientists have a keen interest in understanding whether a core set of processes is unique to tropical cyclogenesis and intensification anywhere around the globe, irrespective of geographic location. TCSP will address many of the issues associated with TC genesis in close proximity to a central mountain chain (the Central American cordillera) and the fate of African Easterly Waves as they interact with this terrain. However, the African Monsoon Meteorology Experiment (AMMA), slated for the eastern Atlantic in summer 2006, provides a potential opportunity to investigate many of the TCSP hypotheses in a different geographical setting. For instance, what is the influence of the Saharan Air Layer on tropical cyclogenesis? Direct NASA participation with one or more ground-based Doppler radars and possibly a high altitude research aircraft stationed downstream of the African continent during AMMA will be ideally suited to better understand why some tropical disturbances develop into Atlantic hurricanes, while others do not. Historically, the most destructive hurricanes that make landfall on U.S. soil originate from Africa during the late summer-early fall.

In addition, NASA has hurricane modeling research in the areas of advanced computational modeling coupled with the space borne observations. A major experiment, in collaboration with NOAA, which combines advanced weather prediction model, satellite observations, and powerful computing platform, is currently underway for the 2005 hurricane season.

Global Precipitation Measurement (GPM): TRMM was originally designed to be a three-year scientific research mission. It is now in its eighth year of operation, having completed all of its original scientific research objectives and more. NASA and the Japan Aerospace Exploration Agency (JAXA) will continue their close collaboration beyond TRMM through establishment of a new advanced capability for the measurement of precipitation globally with the Global Precipitation Measurement mission (GPM). This mission will be a critical component of the International Global Earth Observing System of Systems and will significantly improve upon the temporal and spatial resolution provided by TRMM.

The GPM mission's Core Satellite is planned to carry advanced dual-frequency radar that will provide rain measurements exceeding the capabilities of TRMM. In addition, GPM will use an international constellation of satellites to measure precipitation globally and much more frequently (approximately every three hours) than TRMM. In addition to Japan, Europe, Canada, France, India, South Korea, Taiwan, Brazil, and others have expressed and interest in participating in GPM. A science team is currently in place to study the impact of precipitation variability on specific processes within the atmospheric and/or surface water cycles, water budgets and their closure. The precipitation science team is also interested in studying the rate of water cycling through the atmosphere and surface, and the relationships of linked precipitation-water cycle processes on weather and climate through both forcing and feedback. The range of investigations, in addition to modeling and data analysis, includes algorithm improvements, validation, applications, and education/outreach efforts. GPM is currently targeted for launch in late 2010.

Climate Variability: A subtle impact of extreme weather/climate variation, but with far-reaching consequences, is the El Niño-Southern Oscillation (ENSO). ENSO has its roots in a coupled atmosphere-ocean interaction over the western Pacific, and NASA has been monitoring ENSO with the TRMM and QuickSCAT satellites since the late 1990s. The QuickSCAT satellite provides observations of reversing trade winds that accompany El Niño, and NASA TRMM scientists have investigated several El Niño and La Niña rainfall cycles of varying intensity and duration. No two ENSO events are alike, and continued long-term monitoring of ENSO with TRMM will increase our understanding of ENSO's peculiar variations. Precursors to El Niño such as the short-term Madden-Julian Oscillation (MJO) have been identified through TRMM's unique combination of rain and ocean surface temperature measurements. As the key linkage between MJO and ENSO is established, there is the hope that TRMM data sets will be used to increase the predictability of El Niño and its impacts on the United States.

NASA's TOPEX/Poseidon and Jason–I are measuring ocean surface topography, the MODIS instrument on the EOS platforms also provides high-resolution observation of sea surface temperature. The Estimating of the Circulation and Climate of the Ocean project sponsored by the National Oceanographic Partnership Program is currently assimilating long-term ocean observation data into a physically consistent climate quality data set for the climate variability research. These efforts will be augmented in the future with sea surface salinity data from the Aquarius mission.

One aspect of climate change that has received much attention recently is changes in the Earth's ice covered regions. NASA continues to advance our understanding of these ice processes through a combination EOS missions, e.g., the Ice Cloud and land Elevation Satellite (ICESat), the AMSR instrument on Aqua, and ongoing and planned activities with operational and interagency partners, such as the Navy's SSM/I instrument, our partnership in Canada's RADARSAT mission, and others.

The Research and Analysis Program currently supports—in addition to investigations funded by individual programs—two major climate-variability-related categories of interdisciplinary investigations. These are in the areas of sea level rise and polar feedbacks in the climate system, both of which have been identified as priorities of the Climate Change Science Program and Integrated Earth Observing System (IEOS). We continue to work with our interagency partners to maximize investments in understanding the significant changes that have been occurring in the Polar Regions, particularly in the framework of the upcoming International Polar Year (2007–2008).

Q2. For years, there has been a major focus on the effects of greenhouse gases, the thinning of the ozone, global warming, and the melting of the ice caps. It is my assumption, and please correct me if I am wrong, that one of the functions of a Global Earth Observing System of Systems (GEOSS) initiative would be to monitor such activity?

Q2a. As an interagency and international effort, what effect will budget cuts to NASA's Earth Science program have on this initiative?

A2a. NASA Earth system science results of research and development of space-based observations and improved modeling capacity are recognized as contributing nearly 100 instruments on 30 spacecraft for the International Global Earth Observation System of Systems (GEOSS). NASA Earth science applications are recognized for contributing integrated system solutions to each of the nine societal benefit areas highlighted in both the Strategic Plan for a U.S. Integrated Earth Observation System (IEOS) and the 10-Year Plan for a Global Earth Observation System of Systems. The entire NASA Earth Science budget contributes to goals and objectives of U.S. participation in GEOSS. The contributions of NASA research results to GEOSS is not a separate budget line or project. Thereby, any reductions in Earth Science funding would decrease our contribution to GEOSS. NASA plans to contribute the results of over $1B in Earth system science research and development per the President's budget.

The International GEOSS and the U.S. IEOS include framework architectures that can accommodate and benefit from the observations and predictions/forecasts resulting from NASA research and development of space-based Earth observation systems; including the ground segments, data handling capacity, modeling, computing, knowledge, and applied sciences and system engineering.

Q2b. Is it expected that NASA will continue with the GEOSS initiative in FY 2006 and beyond? At what funding levels?

A2b. NASA's plans for research and development of Earth observation systems include support for national and international priorities and goals, including the U.S. IEOS and International GEOSS. The GEOSS is architected to benefit from the full scope of the results of NASA research and development programs, flight missions and applied sciences partnerships on benchmarking enhancements to integrated system solutions for the nine societal benefit areas. Per the response above, the NASA budget for Earth science is the U.S. contribution to the research and development efforts that contribute to the goals and objectives of serving society as documented in the GEOSS 10-Year Implementation Plan.

Q2c. To date, what role has NASA's Earth Science program played in the Administration's new GEOSS initiative?

A2c. NASA leadership contributed to developing and refining the framework and architecture of the U.S. IEOS and International GEOSS plans. The plans provide guidance in the direction for evolving research capacity (including NASA contributions) to enable improved future operational systems. NASA contributes to the national interagency activity through participation in the U.S. Group on Earth Observation, a subcommittee of the Committee on Environment and Natural Resources (CENR). NASA senior officials serve in the roles of Co-Chair and other positions of the USGEO and as alternate Co-Chair for the Architecture SubGroup of the international Group on Earth Observations.

NASA missions (e.g., Terra, Aqua, and Aura), program plans (e.g., Earth Science strategies and implementation plans) and results (e.g., collaboration with EPA on enhancing the national air quality Nowcasting system) are recognized through the USGEO and GEO as contributions to the IEOS and GEOSS.

Q3. I also have the privilege of serving on the Financial Services Committee and have had the opportunity to take a close look at the Administration's changes to housing programs. The Administration wants to consolidate Community Development Block Grants and six other HUD programs as well as ten other programs from federal agencies to move them into the Commerce department, drastically reducing funding in some cases and making minimal cuts in others. I also notice that in the same fashion at the Administration's request, NASA has decided to combine the Earth Science and solar physics programs into one Earth-Sun Science program that has been incorporated into the new Science Mission Directorate.

a. Which stand-alone projects within the Earth Science program will sustain the most drastic cuts?

b. Do you believe the reorganization of NASA's Earth Science program is a good idea or a bad idea? Why?

c. Would you have any recommendations for improving the effectiveness of NASA's Earth Science program?

A3a,b,c. The combination of the former Earth Science Enterprise and Sun-Earth Connection theme of the Space Science Enterprise into a single unified Earth-Sun System Division has not led to cuts in any Earth science projects. Significant reductions were made between FY 2004 and FY 2005 President's budgets. In FY 2006, the budget submit using the new structure, resulted in no significant reductions to Earth science.

The creation of a single unified Science Mission Directorate and the grouping of the former Earth Science Enterprise and the Sun-Earth Connection theme of the former Space Science Enterprise into a single unified Earth-Sun System Division was done to better position us to take advantages of potential synergies between formally different organizations. However, the time elapsed since the agency transformation that effected these changes is too short to determine whether the benefits are being achieved.

NASA's Earth Science budgets are managed overall effectively. We feel that one of the most important things that can be done to improve management is to assure the stability of the program. Firming up of budgets early in the fiscal year is also very important, as it allows for early establishment of targets.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Berrien Moore III, Director, Institute for the Study of Earth, Oceans, and Space, University of New Hampshire

Questions submitted by Chairman Sherwood L. Boehlert

Q1. In your written testimony, you state that the NAS committee recommends that NASA and NOAA should commission an independent review regarding the Landsat Data Continuity Mission. Please clarify why the committee believes the Administration should perform another cost benefit analysis of the decision to transition the Landsat measurements to the NPOESS platform, as outlined in the Auguest 13, 2004 OSTP memo.

A1. In reference to the Landsat Data Continuity Mission, the Interim Report of the National Academy of Science's Decadal Study team recommended independent external reviews that involved the scientific and operational users that focused upon suitability, capability, and timeliness of the (OLI).

Our understanding of what happened to the Landsat Continuity Mission can be summarized as follows:

Efforts to begin implementing a successor mission to Landsat 7, called the Landsat Data Continuity Mission (LDCM), focused on a plan to purchase data meeting LDCM specifications from a privately owned and commercially operated satellite system beginning in March 2007. However, after an evaluation of proposals received from private industry, NASA canceled a Request-for-Proposals (RFP) for providing the required data in September 2003. Soon after, the Executive Office of the President formed an interagency working group to discuss Landsat data continuity in light of the cancellation. A memorandum from the Office of Science and Technology Policy (OSTP), signed on August 13, 2004 by the Director of OSTP, Dr. John Marburger, III, summarizes the outcome of these discussions. The memorandum states "the Departments of Defense, the Interior, and Commerce and the National Aeronautics and Space Administration have agreed to take the following actions:

- "Transition Landsat measurements to an operational environment through the incorporation of Landsat-type sensors on the National Polar-orbiting Operational Environmental Satellite System (NPOESS) platform;
- "Plan to incorporate a Landsat imager on the first NPOESS spacecraft (known as C–1), currently scheduled for launch in late 2009;
- "Further assess options to mitigate the risks to data continuity prior to the first NPOESS–Landsat mission, including a 'bridge' mission."

We know of no formal study that actually accessed the "bridge mission" nor do we believe that the user community was adequately involved in the formulation of the 13 August 2004 memorandum from OSTP. We certainly applaud the steps of OSTP, NASA, NOAA, and USGS to help assure the longer-term future of Landsat, but we believe that before giving up on the bridge mission and before settling on NPOESS as the implementation platform for OLI, there should be an independent study weighing all the options.

Q2. During the hearing, much of the discussion concerned what the National Oceanic and Atmospheric Administration (NOAA) does not do. Could you please describe the Earth science that NOAA does support, its significance and how it differs from what is done by National Aeronautics and Space Administration (NASA)?

A2. The Earth science accomplished through NOAA support is important and it is, as it should be, focused upon helping NOAA meets its operational mandates. NOAA is a science-based agency with regulatory, operational, and information service responsibilities. To fulfill these responsibilities, it is essential that NOAA maintain a vigorous and forward-looking research enterprise that has both near and longer-term goals, but it must be recognized that the operational (near-term) requirements will always be a significant pressure upon the research enterprise. Moreover, in addition to having to respond to operational concerns, the research budget at NOAA is relatively modest in comparison to the Earth science research effort at NASA. Finally, Earth science depends upon significant technological advances in order to address the critical difficult challenges of today, for which there is no budget nor is there a mandate for NOAA to mount significant technology development programs that are needed to meet today's and tomorrow's scientific and operational challenges.

In sum, the differences are a) NOAA's operational mandate, and b) the relatively modest size of NOAA research budget (a significant portion is consumed by the 30 NOAA Laboratories and Centers and 19 Joint Institutes), and the subsequent lack of a significant capability for advanced technology development.

Q3. What are the advantages and disadvantages of placing NASA instruments on NOAA platforms, assuming that the appropriate funding was provided?

A3. The advantages are increased collaboration, the ability to stage "pre-operational instruments in an operational environment (which should smooth the transfer to operations) and expanded access to space. The main disadvantages are the narrow selection of orbits and launch opportunities, a rather limited envelope for power, weight, and other spacecraft resources, and the potential constraint on data transfer and data processing. In addition, there is a concern that if NASA hands the instrument over to NOAA, NASA then will not provide a Research and Analysis function as it would for a purely NASA mission. This latter issue could be addressed by policy; whereas, the narrow selection of orbits, launches, and space, and ground resources are more troubling.

Questions submitted by Representative Bart Gordon

Q1. What do you consider to be the most promising future benefits that the Nation might gain from continued investments in Earth science research? What will be the negative impacts on society if NASA's commitment to Earth science research and applications is diminished in the coming year?

A1. Future benefits. Improved scientific understanding, which forms the foundation for practical applications that enhance the prosperity and security of society. Businesses, government agencies, and even individuals rely on products and services that have emerged from Earth science research programs. For example, improvements in the ability to forecast weather have had an enormous impact on society. Today's four-day weather forecast is as accurate as two-day forecasts were 20 years ago. The error in the three-day forecast landfall position of hurricanes has been reduced from about 210 miles in 1985 to about 110 miles in 2004. Sea surface winds and precipitation can be observed at accuracies that allow emergency managers to more efficiently evacuate coastal residents in the path of hurricanes. As a result, lives are saved and property losses are minimized. Increased knowledge about the ocean-atmosphere-land system suggests that similar improvements are possible in seasonal climate forecasts, which are needed for a variety of agriculture decisions.

Today, we can track vast clouds of dust and pollution from their source on continents across the oceans, permitting health alarms to be sounded effectively. We can map deformations of the Earth's surface and evacuate regions that may soon experience volcanic eruptions or landslides. We can track changes in soil moisture and then redirect food supplies to areas that may soon face drought and famine. We can monitor long-term changes in the land surface, atmosphere, and oceans and thereby characterize the impacts of human activities on climate. We have documented ozone loss in the stratosphere, resulting in the Montreal Protocol and termination of the production of the causative chlorofluorocarbons (CFCs).

Despite many successes in applying Earth science information to improve lives, security, and the economy, we have the ability to do much more. The increase in knowledge produced over the last decade by Earth scientists is itself a tremendous societal benefit with clear public policy implications. And the experience in applying that knowledge lays a solid foundation for more systematically selecting new missions that address not only important scientific issues but also critical societal needs. New observations, analyses, better interpretive understanding, enhanced predictive models, broadened community participation, and improved means for information dissemination are all needed. If we meet this challenge, we will begin to realize the full economic and security benefits of Earth science.

Negative Impacts. At NASA, the vitality of Earth science and application programs has been placed at substantial risk by a rapidly shrinking budget that no longer supports already-approved missions and programs of high scientific and societal relevance. Opportunities to discover new knowledge about Earth are diminished as mission after mission is canceled, descoped, or delayed because of budget cutbacks. These reductions and the change in priorities jeopardize NASA's ability to fulfill its obligations in (other) important presidential initiatives, such as the Climate Change Research Initiative and the subsequent Climate Change Science Program. It also calls into question future U.S. leadership in the Global Earth Observing System of Systems, an international effort initiated by the current Administration.

This substantial reduction in Earth observation programs today will result in a loss of U.S. scientific and technical capacity, which will decrease the competitiveness of the United States internationally for years to come. U.S. leadership in science, technology development, and societal applications depends on sustaining competence across a broad range of scientific and engineering disciplines that include the Earth sciences.

Questions submitted by Representative Mark Udall

Q1. The White House has proposed putting the Landsat imager on the first NPOESS satellite, currently being developed by NOAA and DOD.

- *What are the technical and programmatic risks of putting the new Landsat imaging sensor on the first NPOESS platform? How serious are those risks?*
- *Is the Landsat user community involved in determining the requirements to be met if the Landsat sensor is added to NPOESS?*

A1. The main technical and programmatic risks are as follows:

a. Technical

1. Adequacy of the large NPOESS platform to adequately meet the pointing and jitter requirements of the Operational Land Imager (OLI).
2. Operational data interface from the Weather Centrals to the land processing system.

b. Programmatic

1. Adequate involvement of the community in the definition of the instrument performance requirements.
2. Impact of delay in the launch of NPOESS C–1 (first) platform, which will compound the impact of the lack of a bridge mission (see my comments attached below that I submitted to one of Chairman Boehlert's questions).
3. Long-term commitment to process and distribute the data.
4. Uncertain policy of response to OLI instrument failure on orbit.

Q2. How do current NASA Earth science budgetary priorities and plans compare to recommendations made by the National Research Council over the past five years?

A2. Simply put, the current direction of Earth sciences is 180 degrees from the recommendations of the Earth sciences community as expressed through NRC reports. NASA is cutting or delaying recommended missions that were in development, and it is not responding to recommendations for other new missions; the Research and Development monies are being cut and opportunities for graduate education are being diminished. By and large, NASA is heading in the opposite direction from repeated recommendations of the Earth sciences community.

Questions submitted by Representative Al Green

Q1. I also have the privilege of serving on the Financial Services Committee and have had the opportunity to take a close look at the Administration's changes to housing programs. The Administration wants to consolidate Community Development Block Grants and six other HUD programs as well as ten other programs from federal agencies to move them into the Commerce department, drastically reducing funding in some cases and making minimal cuts in others. I also notice that in the same fashion at the Administration's request, NASA has decided to combine the Earth science and solar physics programs into one Earth-Sun Science program that has been incorporated into the new Science Mission directorate.

Q1a. Which stand-alone projects within the Earth science program will sustain the most drastic cuts?

A1a. I believe that the Interim report captures the stand-alone projects most severely cut through its list (Table 3.1 from the Interim Report attached below) of missions that are either delayed, canceled, or descoped. In addition, I believe that the next is the Earth System Science Pathfinder program, which currently does not have sufficient funds to execute in a timely fashion the mission that have been selected in the ESSP–3 set and no monies for ESSP–4 Request for Proposals. Addressing the issues implicit in the Table and ESSP would be my top priority.

Q1b. Do you believe the reorganization of NASA's Earth science program is a good idea or a bad idea? Why?

A1b. I do not have a strong view on combining Earth and solar physics—I know that it can work productively since these sciences are combined in a single institute at UNH and they were combined in the 1980s at NASA. I do not think that this is a major issue.

Q1c. Would you have any recommendations for improving the effectiveness of NASA's Earth Science program?

A1c. The development a coherent Decadal View is the next critical step-this is the responsibility of the community through the NRC study. When this is accomplished and adequately reviewed, then I believe that NASA must align its program with that expressed view. For the moment, we must stop the bleeding so that the patient does not die.

TABLE 3.1 Canceled, Descoped, or Delayed Earth Observation Missions

Mission	Measurement	Societal Benefit	Status
Global Precipitation Measurement (GPM)	Precipitation	Reduced vulnerability to floods and droughts; improved capability to manage water resources in arid regions; improved forecasts of hurricanes	Delayed
Atmospheric Soundings from Geostationary Orbit (GIFTS—Geostationary Imaging Fourier Transform Spectrometer)	Temperature and water vapor	Protection of life and property through improved weather forecasts and severe storm warnings	Canceled
Ocean Vector Winds (active scatterometer follow-on to QuikSCAT)	Wind speed and direction near the ocean surface	Improved severe weather warnings to ships at sea; improved crop planning and yields through better predictions of El Niño	Canceled
Landsat Data Continuity—bridge mission (to fill gap between Landsat-7 and NPOESS)	Land cover	Monitoring of deforestation; identification of mineral resources; tracking of the conversion of agricultural land to other uses	Canceled
Glory	Optical properties of aerosols; solar irradiance	Improved scientific understanding of factors that force climate change	Canceled
Wide Swath Ocean Altimeter (on the Ocean Surface Topography Mission; OSTM)	Sea level in two dimensions	Monitoring of coastal currents, eddies, and tides, all of which affect fisheries, navigation, and ocean climate	Instrument canceled—descope of an enhanced OSTM

ANSWERS TO POST-HEARING QUESTIONS

Responses by Timothy L. Killeen, Director, National Center for Atmospheric Research

Questions submitted by Chairman Sherwood L. Boehlert

Q1. During the hearing, much of the discussion concerned what the National Oceanic and Atmospheric Administration (NOAA) does not do. Could you please describe the Earth science that NOAA does support, its significance and how it differs from what is done by National Aeronautics and Space Administration (NASA).

A1. The National Oceanic and Atmospheric Administration (NOAA) plays an important role in performing and supporting Earth science research in the U.S. NOAA and NASA are the only U.S. civil agencies that fund the design, development and operation of Earth observing satellites that provide global-scale measurements of the Earth system, and both agencies also support a wide variety of modeling and research activities that include efforts focused on weather prediction, climate change, and oceans. There are, however, a number of important differences.

NOAA's research focuses mainly on study of the atmosphere and oceans (as the agency name implies), and is largely focused on supporting NOAA's operational mission. NOAA certainly plays a leading role in research relevant to weather prediction, although many other agencies, including NASA and NSF are also active in this area. NOAA plays a very important role in climate change research and, particularly, in climate change observations. NOAA's ongoing work in measuring the CO_2 concentration in the atmosphere is one of the fundamental building blocks of climate change science, with a high quality record that extends back to the late 1950's. Its effort to establish a climate reference network of precise and ideally placed stations to measure temperature, precipitation, and wind speeds will likewise prove very beneficial to scientists and decision-makers if it is strongly supported by the Administration and Congress over the long-term. And NOAA ocean measurements and analyses have helped explain the role of the ocean in storing much of the energy retained in the Earth system as a consequence of the human-induced build-up of greenhouse gases in the Earth's atmosphere. NOAA has also been a leader in improving our understanding of climate variability as well as longer-term climate change. The network of NOAA buoys in the tropical Pacific has helped explain the El Niño-Southern Oscillation and its impacts.

NASA has supported a broader program of Earth science and global change research that includes significant efforts in land use and land cover change, terrestrial ecology, and solid Earth/geology, which are not prominent in NOAA research. In addition to its broader scope, NASA has been a much larger supporter of university-based research. Leaving spacecraft and data system costs aside, AAAS analyses show that NASA was the third largest provider of competitively awarded extra mural funding for the university environmental science community in 2004, trailing only the National Science Foundation and the National Institutes of Health. Even small reductions in the NASA program have large effects in the university community. As I noted in my testimony before the Committee, such reductions have a negative affect on the undergraduate and graduate education and training, and thus on the technical capabilities of our nation's future workforce. In contrast, NOAA is not a significant provider of peer-reviewed competitive research opportunities for the academic community, instead spending most of its research funding on intramural work that is conducted in its own labs.

Q2. What are the advantages and disadvantages of placing NASA instruments on NOAA platforms, assuming that the appropriate funding was provided?

A2. In general, there is no direct scientific advantage to placing NASA instruments on NOAA platforms. There could be budgetary savings for NASA if it did not have to pay for spacecraft development or operation. But NOAA would have to bear these costs, which would require significant increases in the NOAA budget. It does not appear that shifting the responsibility for some part of overall mission costs from one agency to another will reduce the overall expense to taxpayers. The only scenario where one can imagine significant savings is if a single instrument can serve both NOAA and NASA purposes. But the significant differences between NASA science needs and NOAA operational needs make such opportunities difficult to identify.

It is possible that societal benefits could accrue from tighter integration of NASA and NOAA satellite activities related to weather forecasting if such integration resulted in more rapid and effective transition of advanced research capabilities to operations. However, NOAA and NASA activity in this area is already much more integrated than commonly realized, with NASA responsible for the construction, integration, and verification testing of the spacecraft, instruments, and unique ground equipment operated by NOAA. Satellites are handed off to NOAA after they are checked out on-orbit. This responsibility will be taken over by the Air Force when the U.S. begins operation of the joint DOD–NOAA–NASA National Polar-orbiting Operational Environmental Satellite System (NPOESS), which will replace the current generation of polar orbiting weather satellites in about 2008. Provision of NASA research instruments to such a system could provide research and operational benefits, but this requires that the overall program is provided with sufficient budgets and managed in such a fashion that it can ingest and make use of continued advances in capabilities.

There are important Earth science questions that can only be addressed by maintaining accurate space based measurements for very long periods of time, particularly in climate change, solar, and land cover change research. One can make a rational argument that a set of long-term research instruments should be included on NOAA operational satellites that are expected to be maintained as part of our nation's permanent infrastructure. But this only makes sense if there is a long-term budgetary commitment to developing and maintaining the advanced instrumentation needed to produce research-quality measurements. Experience to date is not particularly encouraging in this regard, with Landsat providing an unfortunate example of major difficulties in maintaining long-term support for high-quality research measurements, even when they also serve many practical, nearly "operational" purposes.

It should also be remembered that NASA is currently flying three large Earth science satellite systems carrying a total of 15 different instruments, along with about 14 smaller Earth science missions carrying 1–3 instruments each. NOAA currently operates four satellites at a time. Transferring even a small subset of NASA instrumentation onto NOAA satellites implies a significant increase in the number and/or capabilities of these systems (instruments require power, space, and communications capacity), which will require substantial additional funding over and above the amounts required for instrument design and development. Such a step is also likely to require substantial additions to NOAA staffing, perhaps by transferring large numbers of NASA employees to NOAA. Conversely, significantly reducing the number of research instruments that can be flown would significantly reduce the scope of U.S. efforts to document and understand the planet upon which we live and depend.

The primary disadvantage of flying NASA research instruments on NOAA operational platforms is the difficulty of merging the differing management requirements for operational and research systems. The primary purpose of NOAA systems is protection of life and property, which translates into a set of overarching management requirements. Science will be a junior partner in such systems, and operational requirements are almost certain to override science requirements if there is a conflict between them. This is appropriate, but also represents a potential cost to our nation's science efforts. For example, a key instrument failure requires rapid launch of a replacement NOAA satellite, even if the other instruments are still working. The old satellite is then turned off. Adapting research instrumentation to such a system either requires (a) the purchase of multiple instrument copies so that the "hot spares" can include replacement research instruments or (b) additional research funding to support continued satellite operations if operational instruments fail.

In summary, it is possible that flight of NASA instruments on NOAA satellites could provide benefits to both the science and operational communities, and to our nation as a whole, but only if adequate budgets are provided over the long-term and strong and effective interagency management mechanisms are put in place. Maintaining an appropriate balance of scientific and operational requirements and priorities would be very challenging in such an arrangement, but is critical to achieving success. This kind of program integration is not likely to result in significant overall savings or efficiencies unless single instruments can be made to serve operational and research purposes. Reduction in the budgets devoted to Earth science satellite missions and/or the numbers of Earth science instruments that are developed and operated will slow the rate at which we improve our understanding of the Earth system and how changes in the Earth system affect its capacity to sustain life.

Questions submitted by Representative Bart Gordon

Q1. What do you consider to be the most promising future benefits that the Nation might gain from continued investments in Earth science research? What will be *the negative impacts on society if NASA's commitment to Earth science research and applications is diminished in the coming years?*

A1. As I stated when I testified before the Committee, I believe that rapid advances in NASA Earth observing capabilities, coupled with revolutionary advances in information technology, have positioned us for an extraordinary new era in Earth science research—one in which we can quantitatively understand and predict the Earth as a system, with the temporal and spatial fidelity needed by decision-makers at many levels of our society: local, regional, and global. This will lead directly to major societal benefits including:

- improved national security
- better weather forecasts and warnings
- more targeted climate outlooks
- better management of natural resources including water, agriculture, and energy
- more effective mitigation of natural disasters such as drought, floods, landslides, and volcanic eruptions.

The investments made in Earth science programs at NASA, the National Science Foundation, the National Oceanic and Atmospheric Administration, the Department of Energy, the U.S. Geological Survey, and other agencies are all important for enabling this progress. But NASA plays a unique role in our overall national efforts as the only provider of research-quality (i.e., well documented and very accurate) global scale measurements from space. Reducing our investment in NASA Earth sciences program will slow the rate at which we improve our understanding of the Earth system and how changes in that system affect its capacity to sustain life. Reduced investment will also slow the rate at which we develop new practical applications of scientific knowledge will provide the benefits listed above, even as other nations are increasing their investments and expertise in this area.

Questions submitted by Representative Al Green

Q1. I also have the privilege of serving on the Financial Services Committee and have had the opportunity to take a close look at the Administration's changes to housing programs. The Administration wants to consolidate Community Development Block Grants and six other HUD programs as well as ten other programs from federal agencies to move them into the Commerce department, drastically reducing funding in some cases and making minimal cuts in others. I also notice that in the same fashion at the Administration's request, NASA has decided to combine the Earth science and solar physics programs into one Earth-Sun Science program that has been incorporated into the new Science Mission Directorate.

Q1a. Which stand-alone projects within the Earth science program will sustain the most drastic cuts?

A1a. This question is most appropriately addressed by NASA managers. I do not have access to their internal decision processes about exactly how they will allocate budget reductions that are proposed by the Administration and approved by Congress. As an Earth scientist, I am particularly concerned about a set of actions identified in the recent report from the National Research Council, including:

- Cancellation of the Ocean Vector Winds mission
- Cancellation of the Landsat Data Continuity mission
- Cancellation of the Glory mission
- Cancellation of the Wide Swath Ocean Altimeter
- Cancellation of the Geostationary Imaging Fourier Transform Spectrometer
- Delay of the Global Precipitation Measurement Mission

In a more general sense, I am quite worried about the possibility that additional budget reductions will fall disproportionately on the Research and Analysis component of the NASA program, which supports the involvement of the academic community in NASA programs and enables the creation of knowledge and useful information from space-based measurements.

Q1b. Do you believe the reorganization of NASA's Earth Science program is a good idea or a bad idea? Why?

A1b. I believe that it is up to NASA and those in the Congress and Executive branch who are responsible for oversight of NASA to agree on the most appropriate organizational structure for the Agency and its programs. However, I am concerned that the combination of NASA's Earth and Space science programs into a single organization and the reduction of funding for both Earth and Space science is part of an overall process of reducing NASA science funding and applying it to other agency priorities. I believe this is a serious mistake. In my view, our nation is better served by a balanced NASA program that provides strong support to both science and human space flight and exploration funding, and I would thus respectfully suggest continued maintenance of the traditional "firewall" between science and human space flight funding.

Q1c. Would you have any recommendations for improving the effectiveness of NASA's Earth Science program?

A1c. As I stated when I testified before the Committee, I believe that NASA should work with the scientific and technical community and its partner agencies in the Climate Change Science Program (CCSP) to define a NASA Earth science plan that is fully compatible with the overall CCSP science strategy. In my view, the interaction with the scientific and technical community should include both input from and review by the National Research Council and direct interaction with the community of investigators who are supported by NASA, and the aerospace industry who are very familiar with NASA capabilities and developing technological opportunities. I believe NASA should also find a means of involving users and potential users of NASA-generated data in this process, perhaps through public comment periods or a series of workshops. This science plan should then guide the process of setting mission priorities.

Defining criteria to use in comparing and deciding upon potential mission would be an important part of this planning exercise. I would recommend consideration of a set of criteria that include:

- Compatibility with science priorities in the plan
- Potential scientific return from mission
- Technological risk
- Direct and indirect societal benefits
- Cost.

I believe that the decadal planning activity underway at the NRC in response to a request from NASA and NOAA is a valuable step in this process.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Sean C. Solomon, Director, Department of Terrestrial Magnetism, Carnegie Institution of Washington

Questions submitted by Chairman Sherwood L. Boehlert

Q1. During the hearing, much of the discussion concerned what the National Oceanic and Atmospheric Administration (NOAA) does not do. Could you please describe the Earth science that NOAA does support, its significance and how it differs from what is done by National Aeronautics and Space Administration (NASA)?

A1. There are two fundamental differences between NOAA and NASA. First, NOAA is primarily an operational or monitoring agency, whereas NASA's strength is the ability to develop innovative technologies that enable new types of measurements and new discoveries about how the Earth functions as a planet. Second, NOAA's charter is focused on the oceans and atmosphere, whereas NASA takes a planetary perspective, one that integrates the land surface and interior with the oceans and atmosphere as well as the Earth's space environment. Both NASA and NOAA play important roles for Earth science and for this nation, but those roles are distinct. This nation is stronger because of the complementarity and cooperation between the two agencies.

Q2. What are the advantages and disadvantages of placing NASA instruments on NOAA platforms, assuming that the appropriate funding was provided?

A2. Certainly there are often economies to be gained in situations where NASA can place an instrument on a space platform operated by another federal agency or international partner. Such situations can save the cost of a dedicated satellite and can provide greater access to space flight. The principal disadvantages, in contrast, are that the choice of orbital characteristics, mission operations, or data management for one mission may not be optimum for another experiment, leading to compromises in experiment goals and lessened scientific impact. Each such opportunity needs to be evaluated in light of the full trade-off among benefits and costs.

Questions submitted by Representative Bart Gordon

Q1. What do you consider to be the most promising future benefits that the Nation might gain from continued investments in Earth science research? What will be the negative impacts on society if NASA's commitment to Earth science research and applications is diminished in the coming years?

A1. We still have much to learn about how our planet functions. Continued investment in Earth science can deepen our understanding of how our atmosphere protects and sustains us, how Earth's climate and weather are evolving, what controls the availability of fresh water, how life influences and responds to environmental processes, and what controls changes to the Earth's surface and interior. A diminished investment by this nation in new technologies for studying our planet will impact deleteriously our ability to mitigate natural disasters; make the best use of our land, ocean, and fresh-water resources; and better the lives of all of Earth's citizens.

Questions submitted by Representative Al Green

Q1. I also have the privilege of serving on the Financial Services Committee and have had the opportunity to take a close look at the Administration's changes to housing programs. The Administration wants to consolidate Community Development Block Grants and six other HUD programs as well as ten other programs from federal agencies to move them into the Commerce department, drastically reducing funding in some cases and making minimal cuts in others. I also notice that in the same fashion at the Administration's request, NASA has decided to combine Earth science and solar physics programs into one Earth-Sun Science program that has been incorporated into the new Science Mission Directorate.

- *What stand-alone projects within the Earth science program will sustain the most drastic cuts?*
- *Do you believe the reorganization of NASA's Earth Science program is a good idea or a bad idea? Why?*

- *Would you have any recommendations for improving the effectiveness of NASA's Earth Science program?*

A1. The specific form of organization at NASA is less important than the vision brought to the strategic planning process used to develop mission concepts and prioritize new programs. During the late 1980s and early 1990s the Earth and space sciences were combined into one office at NASA, and all elements of the Agency's sciences programs fared equitably.

There are ongoing efforts at strategic planning that should improve the effectiveness of NASA's program in Earth science and applications. The first decadal survey for Earth science and applications from space, now underway under the aegis of the National Academy of Sciences, is an important indicator that the Earth science community has embraced the need to integrate its planning and prioritization processes. NASA's scientific roadmapping efforts that were completed earlier this year and are now under review by the National Research Council constitute a parallel, complementary strategic planning activity that has produced focused recommendations for the most important next steps for the Agency's Earth Science program.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Marcia McNutt, President and CEO, Monterey Bay Aquarium Research Institute

Questions submitted by Chairman Sherwood L. Boehlert

Q1. During the hearing, much of the discussion concerned what NOAA does not do. Could you please describe the Earth science that NOAA does support, its significance and how it differs from what is done by NASA?

A1. The closest analogy I can make in trying to distinguish the different roles visa-á-vis NOAA and NASA with regard to Earth science is to say that NOAA is the ultimate consumer of scientific information, whereas NASA is a creator of scientific information. As a consumer, NOAA would thrive if it could satisfy its appetite for Earth science information using systems developed, deployed, and operated by other agencies. For many years, NOAA got its space-based Earth science information using NASA satellites, sensors, and data systems. However, NOAA couldn't guarantee that the diet for Earth science data that it had become accustomed to and that it required to meet its mission-specific obligations would always be provided by NASA, given NASA's basic research objectives. Therefore, it made sense for NOAA to replicate satellite missions that NASA had already developed, tested, and proven once the NASA prototypes were no longer serviceable. In fact, this approach was good for both agencies, because it freed up NASA resources in the Earth sciences to work on better, more precise instrumentation and new sensors that could measure important quantities that had never been acquired from space before.

If all that was at stake here was continuing a time series using existing instruments on standard platforms (e.g., the TOMS—Total Ozone Mapping Spectrometer—missions that measure the evolution of the ozone hole), I would be comfortable with the idea that NOAA could pick up that part of the program. However, that is not what is being proposed. Missions in NASA's Earth Science program that are prototypes of new measurements from space are being canceled or indefinitely postponed. NOAA does not have the history or the technology base or the mission to take on these new developments. Furthermore, NASA is developing new sensor systems for Earth science applications that don't necessarily fit with NOAA's oceanic and atmospheric mission (e.g., synthetic aperture radar—SAR—for earthquake and volcano hazard assessment) and that therefore would never be taken up by NOAA. The SAR probably does fit in with the mission of the USGS, but space-based SAR is never going to be developed and brought to operational status by USGS, at least not in any affordable way.

The bottom line is the following. If NOAA were to take on all of NASA's Earth science research program, it would only be successful if it spun up a technology development group in order to create the new sensors and platforms necessary for the next generation of important problems. But this would be a needless and expensive duplication of what NASA is doing already. NASA's mission is to explore the universe. Technology development is essential to achieve that objective. The technology developments needed for exploration and research and (eventually) operations are basically indistinguishable because they are all part of the same continuum. It has made economic sense for many years for NASA to be the technology innovator in Earth sciences, and leave it to the other agencies to adopt and continue the most successful of those programs, as measured by the importance of the acquired data to their missions.

Q2. What are the advantages and disadvantages of placing NASA instruments on NOAA platforms, assuming that the appropriate funding was provided?

A2. I believe that it would be possible to fly a NASA instrument on a NOAA platform IF the platform could support the instrument, IF the orbit were conducive to the measurement being made, and IF NASA were still fundamentally in charge of the development of the instrument and the shepherding of the data stream while the instrument is still in the developmental stages. After all, NASA has done exactly this with other international space agencies, so it should be possible to do this with NASA. But these are a lot of "if's, and as I understand it, this is not what is on the table. NASA has reprogrammed money out of Earth science, so there is no funding to transfer to NOAA to cover the costs, and more than just the launches and the platforms have been cut from the program. The better way to do just this is to leave the funding in a NASA Earth Science program, and create an interagency transfer mechanism to permit NASA Earth Sciences to purchase the launch and the space on a NOAA platform when that indeed is the most cost effective way to accomplish the mission.

Questions submitted by Representative Bart Gordon

Q1. What do you consider to be the most promising future benefits that the Nation might gain from continued investments in Earth science research? What will be the negative impacts on society if NASA's commitment to Earth science research and applications is diminished in the coming years?

A1. Some benefits we can already anticipate because they are already coming over our horizon. For example, I firmly believe that a continued investment in NASA's Earth Science research and application program is critical to the Nation's economy, with the sectors most likely to benefit including energy, agriculture, and transportation. And these are certainly not "fringe" elements of the U.S. economy! What these sectors all have in common is the necessity to make predictions to optimize the scheduling and deployment of resources in order to provide services to society in a cost effective manner. Why plant a crop poorly suited to the projected rain fall in the coming season if another crop will thrive under those same conditions? A largely failed crop is a needless waste of the grower's resources and leads to high prices at the grocery stores for the consumers.

Doubtlessly the most important benefits are the ones that we hardly dare predict yet. But let me be so bold as to suggest an example. The GRACE (Gravity Recovery and Climate Experiment) mission was launched in March, 2002, as part of the Earth System Science Pathfinder program. The GRACE mission detects changes in Earth's gravity field by monitoring the changes in distance between two satellites as they orbit Earth. GRACE's measurements are so precise that the satellite has been able to detect seasonal and longer period changes in groundwater storage beneath the land surface. As a resident of the Salinas Valley, I can attest to the importance of groundwater as a storage mechanism for temporally redistributing fresh water from the season when rain falls—the California winter—to the other seasons when it is needed to grow crops, fight fires, etc. Monitoring changes in water storage in the planet's great aquifers from space makes a lot of sense because the measurement is not limited to locations where there are wells and is insensitive to the complication that where rain falls may be different from where the water is stored. The gravity signal averages out local variations and provides a consistent standard from region to region and continent to continent. Fresh water is one of society's most valuable and threatened resources. I anticipate that missions such as GRACE will be important in helping us properly manage our fresh water supply.

Questions submitted by Representative Al Green

Q1. I also have the privilege of serving on the Financial Services Committee and have had the opportunity to take a close look at the Administration's changes to housing programs. The Administration wants to consolidate Community Development Block Grants and six other HUD programs as well as ten other programs from federal agencies to move them into the Commerce department, drastically reducing funding in some cases and making minimal cuts in others. I also notice that in the same fashion at the Administration's request, NASA has decided to combine the Earth Science and solar physics programs into one Earth-Sun Science program that has been incorporated into the new Science Mission Directorate.

Q1a. Which stand-alone projects within the Earth Science program will sustain the most drastic cuts?

A1a. I will defer to Mr. Diaz to answer this question, as I understand that NASA has not necessarily finalized its plan for which programs will sustain the most drastic cuts and that there are some semantic issues on whether at this point some missions are cut or simply "postponed." However, I will add that in my experience, drawing a project out over a longer time scale adds more to the cost to get the same result. It is not an effective use of resources.

Q1b. Do you believe the reorganization of NASA's Earth Science program is a good idea or a bad idea? Why?

A1b. I think it is a bad idea. I believe that the re-organization has a high likelihood of marginalizing Earth sciences at the Agency. External scrutiny of the distribution of resources between Earth and spaces sciences will be greatly reduced, allowing space science to raid whatever budget is left in Earth science. Like it or not, Earth is the only planet we will have to sustain us for a very long time. NASA's research is so key to our future on this planet that to downgrade its status in the Agency is exactly the opposite of what should be done.

Q1c. Would you have any recommendations for improving the effectiveness of NASA's Earth Science program?

A1c. I am a fan of Goldin's philosophy. I think we should be doing more of the type of research that was encouraged through the Earth System Science Pathfinder (ESSP) program. I prefer that to the large space platforms that try to house every conceivable instrument, and result in undesirable trade-offs in terms of orbit, altitude, etc., and take forever to get launched.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Ray A. Williamson, Research Professor, Space Policy Institute, George Washington University

Questions submitted by Chairman Sherwood L. Boehlert

Q1. During the hearing much of the discussion concerned what the National Oceanic and Atmospheric Administration (NOAA) does not do. Could you please describe the Earth science that NOAA does support, its significance and how it differs from what is done by National Aeronautics and Space Administration (NASA)?

A1. NOAA tends to support applied science, that science that directly supports the needs of the American public, such as weather forecasting, how the U.S. coastline is changing under the effects of global warming, and how periodic medium- and long-term changes in ocean temperature may affect fish and marine populations upon which the U.S. populations depend for sustenance.

NASA, on the other hand conducts research into more basic Earth science questions, such as how space technologies can support basic science research into the underlying Earth systems and how they interact with each other. What are the fundamental mechanisms of weather and climate and how can this knowledge be used to build more accurate weather and climate bio-physical-chemical models of Earth's weather and climate behavior?

Q2. What are the advantages and disadvantages of placing NASA instruments on NOAA platforms, assuming that the appropriate funding was provided?

A2. The answer to this question depends heavily on the precise function of the instrument in question, and the specific orbital parameters of the NOAA spacecraft compared to that of the NASA sensor under consideration. Each orbit has its own particular characteristics. In some cases, an appropriate fit may be found between NASA sensor and NOAA spacecraft. In other cases, the missions of both sensor and spacecraft would have to be compromised substantially in order to put them together. In the case of the Landsat sensor and the Congressional mandate to maintain the continuity of data delivery from the instrument, placing a Landsat-equivalent sensor on the NPOESS satellites means that the Landsat sensor would fly in a different orbit, causing several differences in the characteristics of the data acquired. Extensive experimentation with the resulting data by several different categories of users would be required in order to determine whether or not the differences are sufficient to require major changes in the operational characteristics of the users' data analysis systems. In the long run, such changes in operations might cost more to the users than is saved through placing the instrument on the NPOESS satellites.

Questions submitted by Representative Bart Gordon

Q1. What do you consider to be the most promising future benefits that the Nation might gain from continued investments in Earth science research? What will be the negative impacts on society if NASA's commitment to Earth science research and applications is diminished in the coming years?

A1. Continued investments in Earth science research can, if adequately funded, result in numerous benefits for the Nation, a selection of which are listed below. Conversely, reduced funding can lead to loss of these potential benefits, not only directly from the loss of NASA's involvement in promoting new applications of its research, but also in the loss over the long-term of the scientific knowledge such research provides.

A Partial Selection of Potential Benefits:

- Much improved weather, climate predictability (e.g., 10 days advance forecast in place of the current seven days)
- Improved safety of coastal populations and property at risk from tropical storms through reduced loss of life and property damage
- Improved understanding of the generation, movement, and possible mitigation of greenhouse gases and pollution-causing chemicals
- Contributions to airline safety from space weather forecasts
- Reduced loss of life from improved predictability of earthquakes and volcano activity

- Improved management of natural resources by federal agencies and crop management by agricultural firms

Questions submitted by Representative Mark Udall

Q1. The White House has proposed putting the Landsat imager on the first NPOESS satellite, currently being developed by NOAA and DOD.

Q1a. What are the technical and programmatic risks of putting the new Landsat imaging sensor on the first NPOESS platform? How serious are those risks?

A1a. The current Landsat system is one of the most capable and versatile land observation systems available anywhere. When operating at full capacity, Landsat 7 was capable of producing maps of the entire United States each season, data that are very useful for tracking seasonal changes. Data are used for a wide variety of purposes, from land planning, environmental management, agricultural management, and for large-scale studies of environmental change. They are often the first data sets that users turn to in order to have a general overview of the landscape under study and often serve as a foundation for more detailed analysis with higher resolution data with much less extensive coverage. For the sensor to be placed on the NPOESS satellites, several technical issues would need to be resolved, the details of which depend strongly on the needs of data users, such as orbital height, swath-width of the sensor, the number and placement of spectral channels, and the frequency of coverage. Current users of Landsat data have built their processing and analytic systems around the characteristics of current Landsat data. Hence, any changes in the characteristics of the data sets have far reaching consequences to the many users of Landsat data.

Q1b. Is the Landsat user community involved in determining the requirements to be met if the Landsat sensor is added to NPOESS?

A1b. It is my understanding that the Landsat data user community is generally opposed to placing the Landsat sensor on NPOESS because most users do not feel that it will continue to serve their needs. However, if the Administration decides to move ahead with that transition anyway, the needs of the user community would certainly need to be taken into account in order to encourage those users to continue making use of the data.

Questions submitted by Representative Al Green

Q1. At the Administration's request, NASA has decided to combine the Earth science and solar physics programs into one Earth-Sun science program that has been incorporated into the new Science Mission Directorate.

Q1a. Which stand-alone projects within the Earth Science program will sustain the most drastic cuts?

A1a. This is not a subject with which I have sufficient knowledge to provide an adequate answer.

Q1b. Do you believe the reorganization of NASA's Earth Science program is a good idea or a bad idea? Why?

A1b. In some respects, this is a good idea because it recognizes in the organization the extremely close connection between solar events and their effects on Earth systems. For example, the study of solar-generated space weather, which has been a subject of increasing scientific interest and applied concern because of the sometimes severe effects of space weather on technological systems, such as airline flights and the electricity grid, could be affected positively. Further, the sun, through space weather effects also affects terrestrial weather. However, organizing NASA in this way means that the program managers must give careful attention to coordination of the different aspects of the program to assure that they are able to achieve their overall objectives for the program.

Q1c. Would you have any recommendations for improving the effectiveness of NASA's Earth Science program?

A1c. In my testimony, I noted the importance of following up NASA's Earth Science programs to document the scale and scope of the many benefits we derive from the funds NASA spends on Earth science. In my view, the effectiveness of NASA's Earth Science program would be vastly improved through a sustained effort to document and measure the benefits of Earth science research, both the science results and the applications developed in partnership with other U.S. agencies. As noted in my testimony to this Committee, studies at the Space Policy Institute "show that the supportable, qualitative benefits of Earth science research are quite high to nearly all sectors of industry and to the public sector. Since NASA is at the cutting edge of Earth science research in this country, it should focus more attention on this important subject in order to assist in guiding its future research agenda. This is not to say that expected practical benefits alone should determine NASA's future research agenda, since such an approach might stifle creative, breakthrough research efforts, but such benefits should play a role in the decision process when difficult decisions are being made among projects."

The Committee could assist NASA by "authoriz[ing] NASA to direct greater attention to the quantification of the benefits of Earth science research and applications to America's industry and public sector, and the policy implications of those benefits."

Appendix 2:

Additional Material for the Record

U.S. HOUSE OF REPRESENTATIVES
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109- 716
Space /ETS

April 6, 2005

Chairman Sherwood L. Boehlert
Committee on Science
2320 Rayburn House Office Building
Washington, DC 20515

Dear Chairman Boehlert:

We understand the Committee is planning to hold a hearing this month on Earth Sciences. We encourage you to hold this hearing either before the full Science Committee or as a joint hearing between the Subcommittee on Space and the Subcommittee on Environment, Technology and Standards, because we believe the relevant issues affect both NASA and NOAA.

As you know, reports have surfaced over the past year that parts of NASA's earth sciences program may be transferred to NOAA. The current plan to merge the Landsat program with the National Polar Orbiting Environmental Satellite System program in lieu of NASA pursuing an independent follow-on mission for Landsat demonstrates a willingness to consider new partnerships between these agencies on space-based earth observing systems.

The broad definition of NOAA's mission in H.R. 50 suggests some overlap with the mission defined for NASA in the National Aeronautics and Space Act of 1958. While there may be benefits to having such an overlap, we should explore the implications of this overlap for both agencies. We believe a hearing on the future of earth sciences programs at NASA and NOAA should occur prior to scheduling a markup of H.R. 50, the NOAA Organic Act so that there is sufficient time to consider the implications of the hearing findings for NOAA. The question of whether earth science programs should be transferred to NOAA should be explicitly addressed at the hearing.

Chairman Sherwood L. Boehlert
Page 2
April 6, 2005

We look forward to working with you to shape NASA and NOAA's policies and programs related to earth observations and science. Thank you for your consideration.

Sincerely,

BART GORDON
Ranking Member,
Committee on Science

MARK UDALL
Ranking Member,
Space and Aeronautics
Subcommittee

DAVID WU
Ranking Member,
Environment, Technology
& Standards Subcommittee

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April 19, 2005

The Honorable Bart Gordon
2304 Rayburn House Office Building
Washington, DC 20515

The Honorable Mark Udall
240 Cannon House Office Building
Washington, DC 20515

The Honorable David Wu
1023 Longworth House Office Building
Washington, DC 20515

Dear Congressmen:

Thank you for your letter of April 6 about the pending Science Committee hearing on Earth Science at the National Aeronautics and Space Administration (NASA). This hearing is now scheduled to be held at Full Committee on April 28.

I share the concerns about Earth Science that prompted your letter. I believe that Earth Science is a central mission for NASA and that its Earth Science programs should not migrate to the National Oceanic and Atmospheric Administration (NOAA). H.R. 50 does not contemplate any significant movement of that sort. Certainly NASA and NOAA should improve their level of cooperation, but that is a far cry from any wholesale programmatic transfer.

But the purpose of the April 28 hearing is to give the Committee a chance to learn about the status of NASA's own Earth Science programs and missions and how much rests on their success. Widening (or narrowing) the hearing's scope to deal with the relationship between NASA and NOAA is likely to distract from the central focus of the hearing.

Moreover, the Committee has already heard from experts on NOAA's programs and on one proposal to transfer NASA programs to NOAA. Testimony was received on that issue at our May 5, 2004 hearing on the U.S. Commission on Ocean Policy Preliminary Report and at the Environment, Technology and Standards Subcommittee July 15, 2004 hearing about the NOAA Organic Act.

I would be happy to schedule another hearing that would bring in the two agencies to talk about their respective responsibilities. I think that hearing would be more productive after the April 28 session, which will familiarize Members with the needs of Earth Science and the role NASA plays in that field. A hearing concerning the two agencies also would be more productive after the new NASA Administrator has had time to think through these issues.

However, I do not believe that such a hearing needs to happen before the mark-up of H.R. 50. As I noted above, H.R. 50 in no way assumes, or gives a green light to any large programmatic transfer. I would be happy to work with you on bill or report language to clarify the mission of NOAA with respect to Earth Science programs.

As always, I look forward to working with all of you as we move ahead.

Sincerely,

SHERWOOD BOEHLERT
Chairman

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Earth Science and Applications from Space: Urgent Needs and Opportunities to Serve the Nation

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Committee on Earth Science and Applications from Space:
A Community Assessment and Strategy for the Future

Space Studies Board
Division on Engineering and Physical Sciences

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COMMITTEE ON EARTH SCIENCE AND APPLICATIONS FROM SPACE: A COMMUNITY ASSESSMENT AND STRATEGY FOR THE FUTURE

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SPACE STUDIES BOARD

Preface

In response to requests from NASA, NOAA, and the USGS, the National Research Council has begun a decadal survey of Earth science and applications from space. Developed in consultation with members of the Earth science community, the guiding principle for the study is to set an agenda for observations in support of Earth science and applications from space in which attaining practical benefits for humankind plays a role equal to that of acquiring new knowledge about Earth.[1] These benefits may range from access to information that can satisfy short-term needs for weather warnings for the protection of life and property, to the development of longer-term scientific understanding that is the lifeblood of future societal applications, the details of which are not predictable.

Among the key tasks in the charge to the Committee on Earth Science and Applications from Space are the requests to:

- Develop a consensus on the top-level scientific questions that should provide the focus for Earth and environmental observations in the period 2005-2015; and
- Develop a prioritized list of recommended space programs, missions, and supporting activities to address these questions.

The committee's final report, expected in late 2006, will address these tasks as well as the others described in Appendix A.[2] The purpose of this brief interim report, which was requested by the sponsors of the study and by members of congressional staff, is to provide an early indication of urgent, near-term issues that require attention prior to publication of the committee's final report.

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[1] Development of the vision for the study drew on information received in response to a widely distributed request for comments; town-hall style discussions at the December 2004 meeting in San Francisco of the American Geophysical Union and the January 2005 meeting in San Diego of the American Meteorological Society; committee discussions at a workshop held on August 23-25, 2004, in Woods Hole, Mass.; and discussions at two committee meetings held on November 8-9, 2004, in Washington, D.C., and January 4-6, 2005, in Irvine, Calif.

[2] The final report will also draw on the work of seven study panels organized according to the following themes to address all of the elements of the statement of task (see Appendix A): (1) Earth science applications and societal needs, (2) ecosystem health and biodiversity, (3) weather (including chemical weather), (4) climate variability and change, (5) water resources and the global hydrologic cycle, (6) human health and security, and (7) solid-Earth hazards, resources, and dynamics.

Acknowledgment of Reviewers

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's (NRC's) Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their participation in the review of this report:

Judith Curry, Georgia Institute of Technology,
Lennard A. Fisk, University of Michigan,
Christopher O. Justice, University of Maryland,
Pamela A. Matson, Stanford University,
Norine E. Noonan, College of Charleston,
David T. Sandwell, Scripps Institution of Oceanography, and
Paul D. Try, Science and Technology Corporation.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Carl Wunsch, Massachusetts Institute of Technology, and Robert A. Frosch, Harvard University. Appointed by the National Research Council, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Contents

Executive Summary

Understanding the complex, changing planet on which we live, how it supports life, and how human activities affect its ability to support life in the future is one of the greatest intellectual challenges facing humanity. It is also one of the most important for society as it seeks to achieve prosperity and sustainability.

The decades of the 1980s and 1990s saw the emergence of a new paradigm for understanding our planet—observing and studying Earth as a system of interconnected parts including the land, oceans, atmosphere, biosphere, and solid Earth. At the same time, satellite observing systems came of age and produced new and exciting perspectives on Earth and how it is changing. By integrating data from these new observation systems with in situ observations, scientists were able to make steady progress in the understanding of and ability to predict a variety of natural phenomena, such as tornadoes, hurricanes, and volcanic eruptions, and thus help mitigate their consequences. Decades of investments in research and the present Earth observing system have also improved health, enhanced national security, and spurred economic growth by supplying the business community with critical environmental information.

Yet even this progress has been outpaced by society's ongoing need to apply new knowledge to expand its economy, protect itself from natural disasters, and manage the food and water resources on which its citizens depend. The aggressive pursuit of understanding Earth as a system—and the effective application of that knowledge for society's benefit—will increasingly distinguish those nations that achieve and sustain prosperity and security from those that do not. In this regard, recent changes in federal support for Earth observation programs are alarming. At NASA, the vitality of Earth science and application programs has been placed at substantial risk by a rapidly shrinking budget that no longer supports already-approved missions and programs of high scientific and societal relevance. Opportunities to discover new knowledge about Earth are diminished as mission after mission is canceled, descoped, or delayed because of budget cutbacks, which appear to be largely the result of new obligations to support flight programs that are part of the Administration's vision for space exploration. In addition, transitioning of the scientific successes at NASA into operational capabilities at NOAA and other agencies has failed repeatedly, even as the United States has announced that it will take a leadership role in international efforts to develop integrated, global observing systems.

The Committee on Earth Science and Applications from Space affirms the imperative of a robust Earth observation and research program to address such profound issues as the sustainability of human life on Earth and to provide specific benefits to society. Achieving these benefits further requires that the observation and science program be closely linked to decision support structures that translate knowledge into practical information matched to and cognizant of society's needs. The tragic aftermath of the 2004 Asian tsunami, which was detected by in situ and space-based sensors that were not coupled to an appropriate warning system in the affected areas of the Indian Ocean, illustrates the consequences of a break in the chain from observations to the practical application of knowledge.

The committee's vision for the future is clear: The nation should meet the grand challenge of effectively enhancing and applying scientific knowledge of the Earth system both to increase fundamental understanding of our home planet and how it sustains life and to meet increasing societal needs. This vision reflects and supports established national and international objectives, built around the presidential directives that guide the U.S. climate and Earth observing system initiatives. Realizing the vision requires a strong, intellectually driven Earth sciences program and an integrated land- and space-based observing system—the foundation essential to developing knowledge of Earth, predictions, and warnings—as well as better decision-support tools to transform new knowledge into societal benefits and more effectively link science to applications. The payoff for our nation and for the world is enormous.

EARTH OBSERVATION TODAY

The current U.S. civilian Earth observing system centers on the environmental satellites operated by NOAA;[1] the atmosphere-, biospheres-, ocean-, ice-, and land-observation satellites of NASA's Earth Observing System[2] (EOS); and the Landsat satellites, which are operated by a cooperative arrangement involving NASA, NOAA, and the U.S. Geological Survey (USGS). Today, this system of environmental satellites is at risk of collapse. Although NOAA has plans to modernize and refresh its weather satellites, NASA has no plan to replace its EOS platforms after their nominal 6-year lifetimes end (beginning with the Terra satellite in 2005), and it has canceled, descoped, or delayed at least six planned missions, including the Landsat Data Continuity mission.

These decisions appear to be driven by a major shift in priorities at a time when NASA is moving to implement a new vision for space exploration. This change in priorities jeopardizes NASA's ability to fulfill its obligations in other important presidential initiatives, such as the Climate Change Research Initiative and the subsequent Climate Change Science Program. It also calls into question future U.S. leadership in the Global Earth Observing System of Systems, an international effort initiated by the current Administration. The nation's ability to pursue a visionary space exploration agenda depends critically on its success in applying knowledge of Earth to maintain economic growth and security at home.

Moreover, a substantial reduction in Earth observation programs today will result in a loss of U.S. scientific and technical capacity, which will decrease the competitiveness of the United States internationally for years to come. U.S. leadership in science, technology development, and societal applications depends on sustaining competence across a broad range of scientific and engineering disciplines that include the Earth sciences.

In this interim report, the committee identifies a number of issues that require immediate attention in the FY 2006 and FY 2007 budgets:

- Proceed with some NASA missions that have been delayed or canceled,
- Evaluate plans for transferring needed capabilities from some canceled or descoped NASA missions to NPOESS,
- Develop a technological base for exploratory Earth observation systems,
- Reinvigorate the Explorer missions program,
- Strengthen research and analysis programs, and
- Strengthen the approach to obtaining important climate observations and data records.

The committee's final report, expected in late 2006, will identify high-priority Earth observing system investments for the next decade.

ACTIONS TO MEET CURRENT CRITICAL NEEDS

Proceed with Missions That Have Been Delayed or Canceled

Recently, six NASA missions with clear societal benefits and established support of the Earth science and applications community have been delayed, descoped, or canceled. Two of these missions should proceed immediately:

[1] See discussion at the NOAA Web site at <http://www.nesdis.noaa.gov/satellites.html>.

[2] EOS is composed of a series of satellites, a science component, and a data system supporting a coordinated series of polar-orbiting and low-inclination satellites for long-term global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans. See "The Earth Observing System," at <http://eospso.gsfc.nasa.gov/>.

- *Global Precipitation Measurement (GPM).* The Global Precipitation Measurement mission is an international effort to improve climate, weather, and hydrological predictions through more accurate and more frequent precipitation measurements. GPM science will be conducted through an international partnership led by NASA and the National Space Development Agency (NASDA) of Japan. Water cycling and the availability of fresh water resources, including their predicted states, are of critical concern to all nations, and precipitation is the fundamental driver of virtually all water issues, including those concerned with national security. GPM is the follow-on to the highly successful Tropical Rainfall Measuring Mission, which is nearing the end of operations.[3] It is an approved mission that has been delayed several times by NASA.

The committee recommends that the Global Precipitation Measurement mission be launched without further delays.

- *Atmospheric Soundings from Geostationary Orbit (GIFTS).* The Geostationary Imaging Fourier Transform Spectrometer (GIFTS) will provide high-temporal-resolution measurements of atmospheric temperature and water vapor, which will greatly facilitate the detection of rapid atmospheric changes associated with destructive weather events, including tornadoes, severe thunderstorms, flash floods, and hurricanes. The GIFTS instrument has been built at a cost of approximately $100 million, but the mission has been canceled for a variety of reasons. However, there exists an international opportunity to launch and test GIFTS.

The committee recommends that NASA and NOAA complete the fabrication, testing, and space qualification of the GIFTS instrument and that they support the international effort to launch GIFTS by 2008.

Three other missions—Ocean Vector Winds, Landsat Data Continuity, and Glory—as well as development of enabling technology such as the now canceled wide-swath ocean altimeter, should be urgently reconsidered, as described below.

Evaluate Plans Needed for Transferring Capabilities to NPOESS

Instruments on the following three canceled missions may be either transferred from NASA or replaced with other instruments for flight on the National Polar-orbiting Operational Environmental Satellite System (NPOESS). This approach has both advantages (e.g., transfer of research capabilities to operational use) and disadvantages (e.g., decrease in instrument capability, gaps in data continuity).

- *Ocean Vector Winds.* Global ocean surface vector wind observations have enhanced the accuracy of severe storm warnings, including hurricane forecasts, and have improved crop planning as a result of better El Niño predictions. Such observations are achievable from proven space-borne scatterometer systems. However, NASA has canceled the Ocean Vector Winds mission, a previously planned follow-on to the active scatterometer currently operating on the QuikSCAT mission, which has already exceeded its design life. NOAA is currently planning to use a *passive* microwave sounder, CMIS (Conical Scanning Microwave Imager/Sounder), which will be launched on NPOESS, to recover ocean wind measurements. Tests of the feasibility of this technique are underway based on use of a similar instrument on the Navy's Windsat satellite.
- *Landsat Data Continuity.* For more than 30 years, Landsat satellites have collected data on Earth's continental surfaces to support Earth science research and state and local government efforts to assess the quality of terrestrial habitats, their resources, and their degradation due to human activity.

[3] National Research Council, *Assessment of the Benefits of Extending the Tropical Rainfall Measuring Mission: A Perspective from the Research and Operations Communities*. National Academies Press, Washington, D.C., in press.

These data constitute the longest continuous record of Earth's surface as seen from space. The Land Remote Sensing Policy Act of 1992 directs NASA and the USGS to assess various system development and management options for a satellite system to succeed Landsat 7. The president's budget for NASA for FY 2006 discontinues plans for launch of this satellite system and instead directs NASA to assume responsibility for providing two Operational Land Imager (OLI) instruments for delivery to NPOESS (the second OLI is to be delivered 2 years after the first).

- *Glory*. Glory carries two instruments—the Advanced Polarimetric Sensor (APS) and the Total Irradiance Monitor (TIM). Part of the framework of the president's Climate Change Research Initiative, Glory was developed to measure aerosol properties (via the APS) with sufficient accuracy and coverage to quantify the effect of aerosols on climate. Aerosol forcing is one of the most important sources of uncertainty in climate prediction. Glory would also monitor the total solar irradiance. Measurements of total solar irradiance are needed to understand how the Sun's energy output varies and how these variations affect Earth's climate. TIM would ensure continuity of this important time-series should the irradiance monitor on the Solar Radiation and Climate Experiment (SORCE) satellite fail prior to the launch of NPOESS.

The committee recommends that NASA and NOAA commission three independent reviews, to be completed by October 2005, regarding the Ocean Vector Winds, Landsat Data Continuity, and Glory missions. These reviews should evaluate:

- **The suitability, capability, and timeliness of the OLI and CMIS instruments to meet the research and operational needs of users, particularly those that have relied on data from Landsat and QuikSCAT;**
- **The suitability, capability, and timeliness of the APS and TIM instruments for meeting the needs of the scientific and operational communities;**
- **The costs and benefits of launching the Landsat Data Continuity and Glory missions prior to or independently of the launch of the first NPOESS; and**
- **The costs and benefits of launching the Ocean Vector Winds mission prior to or independently of the launch of CMIS on NPOESS.**

If the benefits of an independent NASA mission(s) cannot be achieved within reasonable costs and risks, the committee recommends that NASA build the OLI (two copies, one for flight on the first NPOESS platform[4]), APS, and TIM instruments and contribute to the costs of integrating them into NPOESS. APS, TIM, and the first copy of OLI should be integrated onto the first NPOESS platform to minimize data gaps and achieve maximum utility.

The reviews could be conducted under the auspices of NASA and NOAA external advisory committees or other independent advisory groups and should be carried out by representative scientific and operational users of the data, along with NOAA and NASA technical experts.

Develop a Technological Base for Exploratory Earth Observation Systems

Much of the recent progress in understanding Earth as an integrated system has come from NASA's Earth Observing System (EOS), which is composed of three multi-instrumented platforms (Terra, Aqua, and Aura) and associated smaller missions.[5] Initial plans, made in the 1980s, called for

[4] The Landsat Data Continuity mission called for the procurement of two instruments, each with a mission lifetime of 5 years, to provide continuity to the Landsat 7 data set.

[5] NASA's Mission to Planet Earth (MTPE) began as an attempt to monitor the entire Earth and continuously evaluate global change trends. In effect, MTPE was a program to evaluate the sustainability of human life on Earth via a study of the interrelated and complex processes involving Earth's geosphere, atmosphere, hydrosphere, and

three series of each of the platforms to ensure a 15-year record of continuous measurements of the land surface, biosphere, solid Earth, atmosphere, and oceans. However, by the late 1990s, budget constraints and other factors led NASA to abandon plans for follow-ons to the first series of EOS satellites. Knowledge anticipated from analysis of EOS long-term data records depends now on a precarious plan to use instruments on the nation's next generation of weather satellites—NPOESS, scheduled for launch in 2009, and a new GOES series, scheduled for launch in 2012—foreign missions, and the occasional launch of small Explorer-class missions. In fact, aside from several delayed Explorer-class missions, the Ocean Surface Topography Mission (a follow-on to the current Jason-1 mission), and the Global Precipitation Measurement mission, the NASA program for the future has no explicit set of Earth observation mission plans.

The committee's final report will include a prioritized list of new Earth observing missions and capabilities. In the meantime, a healthy scientific and technological base for future missions must be maintained.

- *Enabling technology base.* The paucity of missions in active planning mode undercuts the observational capability for which a strong enabling technology base is essential. Particularly disturbing is the absence of development activities for identified measurement capabilities that have been extensively studied, vetted within the community, and endorsed by NASA. For example, interferometric synthetic aperture radar (InSAR) technology now exists in Europe and Canada to monitor small changes in Earth's surface that might presage a volcanic eruption or earthquake, but development of L-band technology will be required to overcome the limitations of current instruments for observing in vegetated areas. Radar interferometry (wide-swath altimetry) was also being developed to monitor coastal currents, eddies, and tides, which affect fisheries, navigation, and ocean climate, but a planned mission was canceled. Another European technology measures winds in the troposphere using an ultraviolet laser, but active remote sensing techniques for such measurements are not yet ready in the United States.

The committee recommends that NASA significantly expand existing technology development programs to ensure that new enabling technologies for critical observational capabilities, including interferometric synthetic aperture radar, wide-swath ocean altimetry, and wind lidar, are available to support potential mission starts over the coming decade.

Reinvigorate the NASA Earth Explorer Missions Program

NASA developed its Earth System Science Pathfinder (ESSP) program as "an innovative approach for addressing Global Change Research by providing periodic 'Windows of Opportunity' to accommodate new scientific priorities and infuse new scientific participation into the Earth Science Enterprise. The program is characterized by relatively low to moderate cost, small to medium sized missions that are capable of being built, tested and launched in a short time interval."[6] ESSP missions were intended to be launched at a rate of one or more per year.

ESSP missions provide a mechanism for developing breakthrough science and technology that enables future societal benefits and for ensuring that human capital is maintained for future missions. For example, the Gravity Recovery and Climate Experiment (GRACE) mission measured time-varying gravity changes up to 100,000 times smaller than those measured previously and provided the first measurements of variations in groundwater storage at continental scales.[7] New ESSP missions within this

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biosphere. The space-based component of MTPE, the Earth Observing System (EOS), was the centerpiece of MTPE; it began formally in early 1990s.

[6] See information on the Earth System Science Pathfinder program at <http://earth.nasa.gov/essp/>.

[7] See M. Cheng and B.D. Tapley, 2004, "Variations in the Earth's Oblateness During the Past 28 Years," *JGR-Solid Earth* 109(N9): B09402. Also see "GRACE Science Papers" on the GRACE home page at <http://www.csr.utexas.edu/grace/publications/papers/>.

program need to be initiated on a frequent basis to fuel innovation,[8] and missions must be launched soon after selection to keep the technology from becoming obsolete. Some of the missions now being planned may not be launched until nearly 10 years after they were selected.

The committee supports continuation of a line of Explorer-class missions directed toward advancing understanding of Earth and developing new technologies and observational capabilities, and urges NASA to:

- **Increase the frequency of Explorer selection opportunities and accelerate the ESSP-3 missions by providing sufficient funding for at least one launch per year, and**
- **Release an ESSP-4 announcement of opportunity in FY 2005.**

Strengthen Research and Analysis Programs

The committee is concerned that a significant reallocation of resources for the research and analysis (R&A)[9] programs that sustain the interpretation of Earth science data has occurred either as a result of the removal of the "firewall" that previously existed between flight and science programs or as an unintended consequence of NASA's shift to full-cost accounting. Because the R&A programs are carried out largely through the nation's research universities, there will be an immediate and deleterious impact on graduate student, postdoctoral, and faculty research support. The long-term consequence will be a diminished ability to attract and retain students interested in using and developing Earth observations. Taken together, these developments jeopardize U.S. leadership in both Earth science and Earth observations, and they undermine the vitality of the government-university-private sector partnership that has made so many contributions to society.

Strengthen Baseline Climate Observations and Climate Data Records

The nation continues to lack an adequate foundation of climate observations that will lead to a definitive knowledge about how climate is changing and will provide a means to test and systematically improve climate models. NASA and NOAA should enhance their observing systems to ensure that there are long-term, accurate, and unbiased benchmark climate observations for a well-defined set of critical climate variables, including atmospheric temperature and water vapor, spectrally resolved Earth radiances, and incident and reflected solar irradiance.

The committee recommends that NASA, NOAA, and other agencies as appropriate accelerate efforts to create a sustained, robust, integrated observing system that includes at a minimum an essential baseline of climate observations, including atmospheric temperature and water vapor, spectrally resolved Earth radiances, and incident and reflected solar irradiance.

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[8] This approach corresponds to the original intent of the Earth System Science Pathfinder program, which solicited proposals every 2 years for satellite measurements that were outside the scope of approved Earth science missions. Proposals were solicited in all Earth science disciplines, from which two missions and one alternate were selected based on scientific priority and technical readiness.

[9] R&A has customarily supplied funds for enhancing fundamental understanding in a discipline and stimulating the questions from which new scientific investigations flow. R&A studies also enable conversion of raw instrument data into fields of geophysical variables and are an essential component in support of the research required to convert data analyses to trends, processes, and improvements in simulation models. They are likewise necessary for improving calibrations and evaluating the limits of both remote and in situ data. Without adequate R&A, the large and complex task of acquiring, processing, and archiving geophysical data would go for naught. Finally, the next generation of earth scientists—the graduate students in universities—are often educated by performing research that has originated in R&A efforts. See National Research Council, 1995, *Earth Observations from Space: History, Promise, and Reality (Executive Summary)*, National Academy Press, Washington, D.C.

Finally, as recommended in previous National Research Council reports, an expanded set of long-term, accurate climate data records should continue to be produced to monitor climate variability and change. A climate data and information system for NPOESS is needed that will make it possible to assemble relevant observations, remove biases, and distribute and archive the resulting climate data records. A corresponding research and analysis effort is also needed to understand what these records indicate about how Earth is changing.

The committee recommends that NOAA, working with the Climate Change Science Program and the international Group on Earth Observations, create a climate data and information system to meet the challenge of ensuring the production, distribution, and stewardship of high-accuracy climate records from NPOESS and other relevant observational platforms.

Today the nation's Earth observation program is at risk. If we succeed in implementing the near-term actions recommended above and embrace the challenge of developing a long-term observation strategy that effectively recognizes the importance of societal benefits, a strong foundation will be established for research and operational Earth sciences in the future, to the great benefit of society—now and for generations to come.

1
Science for the Benefit of Society

The Earth's well-being is also an issue important to America. And it's an issue that should be important to every nation in every part of our world.
President George W. Bush discussing climate change on June 11, 2001.[1]

Progress in Earth science over the last two decades has been dramatic, a consequence of decisions made in the 1980s to study Earth as a system.[2] Research in Earth system science has led to remarkable insights and new lines of inquiry based on how Earth's atmosphere, oceans, and land interact and operate as a whole.

This improved scientific understanding also forms the foundation for practical applications that enhance the prosperity and security of society. Businesses, government agencies, and even individuals rely on products and services that have emerged from Earth science research programs. For example, improvements in the ability to forecast weather (Sidebar 1.1) have had an enormous impact on society. Today's 4-day weather forecast is as accurate as 2-day forecasts were 20 years ago.[3] The error in the 3-day forecast landfall position of hurricanes has been reduced from about 210 miles in 1985 to about 110 miles in 2004.[4] Sea surface winds and precipitation can be observed at accuracies that allow emergency managers to more efficiently evacuate coastal residents in the path of hurricanes. As a result, lives are saved and property losses are minimized. Increased knowledge about the ocean-atmosphere-land system suggests that similar improvements are possible in seasonal climate forecasts, which are needed for a variety of agriculture decisions.[5]

Although weather and seasonal climate forecasts are a prominent example, Earth science knowledge has many other important applications. Today, we can track vast clouds of dust and pollution from their source on continents across the oceans, permitting health alarms to be sounded effectively. We can map deformations of Earth's surface and evacuate regions that may soon experience volcanic eruptions or landslides. We can track changes in soil moisture and then redirect food supplies to areas that may soon face drought and famine. We can monitor long-term changes in the land surface, atmosphere, and oceans and thereby characterize the impacts of human activities on climate. We have documented ozone loss in the stratosphere, resulting in the Montreal Protocol and termination of the production of the causative chlorofluorocarbons (CFCs). As these examples show, Earth information is essential to ensuring the prosperity and security of society as a whole.

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[1] See <http://www.whitehouse.gov/news/releases/2001/06/20010611-2.html>.

[2] For example, the report that led to NASA's Earth system science approach was *Earth System Science, A Program for Global Change*, Report of the Earth System Sciences Committee, NASA, Washington, D.C., 1988.

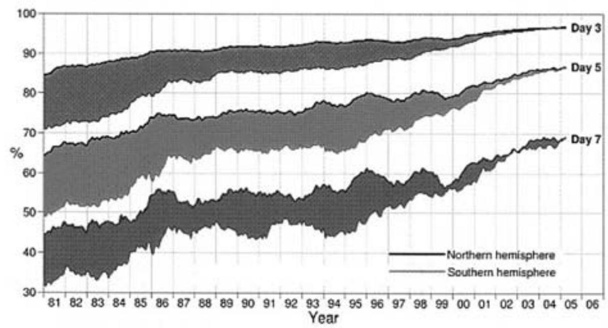
[3] National Weather Service statistics presented in National Research Council, *Satellite Observations of the Earth's Environment: Accelerating the Transition of Research to Operations*, The National Academies Press, Washington, D.C., pp. 24-25, 2003.

[4] L. Uccellini, NOAA National Centers for Environmental Prediction Advisory Panel meeting, January 12, 2005.

[5] The 1997-1998 El Niño created torrential rains in California and led to rapid increases in food costs. See Kenneth Howe, "El Nino's Costly Crops," *San Francisco Chronicle*, February 26, 1998. Changes in sea temperature and sea surface topography observed by satellites and ocean moorings are critical for forecasting the strength and timing of impending El Niño events. Improved forecasts of the 1997-1998 El Niño event are estimated to have saved California residents on the order of $1 billion compared to the costs of a similar event in 1982-1983, which was not forecast. See "The Economic Impacts of an El Nino," *Space Daily*, March 18, 2002, <http://www.spacedaily.com/news/pacific-02g.html>.

Sidebar 1.1 Improvements in Weather Forecasting Resulting from Satellite Observations

One of the greatest societal benefits provided by Earth sciences in the past 30 years has been the steady improvement of weather forecasts. The chart shows the monthly moving average of the correlation (a perfect forecast is 100 percent) between observed and forecast weather features for 3-day, 5-day, and 7-day forecasts. The accuracy of forecasts of large-scale weather patterns in both hemispheres has been increasing steadily from 1980 to 2004. The Southern Hemisphere forecast (bottom curve), which was significantly worse than the Northern Hemisphere forecast (top curve) in 1980, has caught up in accuracy in recent years. This dramatic improvement has been due largely to more and better global satellite data.



SOURCE: A.J. Simmons and A. Hollingsworth, 2002, "Some Aspects of the Improvement in Skill of Numerical Weather Prediction," *Q. J. R. Meteorol. Soc.* 128: 647-678.

Yet the more we apply this knowledge and observe its benefits, the more we identify new needs for basic knowledge, Earth information, credible forecasts, and decision-support structures designed to serve society. Businesses and national infrastructure elements, from transportation to energy, have a critical need for improved weather information.[6] Governments have obligations to manage new environmental treaties and regulations. Much of the U.S. and world population lives in areas that are subject to natural disasters, including hurricanes, tornadoes, floods, earthquakes, and tsunamis. Better forecasts are essential to protect lives and property from such disasters. Improved satellite observations of disaster areas can also speed relief and rebuilding efforts (Sidebar 1.2).[7] Finally, effective management

[6] It is estimated that 30 percent of the U.S. economy is sensitive to weather and climate. See Bureau of Economic Analysis figures reported in National Research Council, *The Atmospheric Sciences Entering the Twenty-First Century*, National Academy Press, Washington, D.C., p. 25, 1998. A weather forecast indicating a one-degree improvement in temperature is estimated to save companies generating electricity about $35 million per year. See R.A. Williamson, H.R. Hertzfeld, and A. Sen, *Future Directions in Satellite-Derived Weather and Climate Information for the Electric Energy Industry: A Workshop Report*, Space Policy Institute, George Washington University, June 2004, <http://www2.gwu.edu/~spi/energy.pdf>.

[7] For example, warning times for tornadoes have increased by 8 minutes since 1978. See National Weather Service statistics presented in National Research Council, *Satellite Observations of the Earth's Environment: Accelerating the Transition of Research to Operations*, The National Academies Press, Washington, D.C., pp. 24–

of natural resources—from clean water to oil and gas reserves to plants and animals—depends critically on the availability of better information and tools.

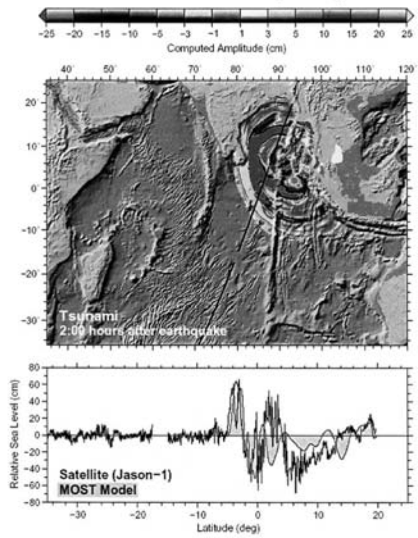
Despite many successes in applying Earth science information to improve lives, security, and the economy, we have the ability to do much more. The increase in knowledge produced over the last decade by Earth scientists is itself a tremendous societal benefit with clear public policy implications (Sidebar 1.3). And the experience in applying that knowledge lays a solid foundation for more systematically selecting new missions that address not only important scientific issues but also critical societal needs.

A central responsibility for the coming decade is to ensure that established societal needs help guide scientific priorities more effectively, and that emerging scientific knowledge is actively applied to obtain societal benefits. New observations, analyses, better interpretive understanding, enhanced predictive models, broadened community participation, and improved means for information dissemination are all needed. If we meet this challenge, we will begin to realize the full economic and security benefits of Earth science.

25, 2003. In addition, volcanic eruptions, landslides, and tsunamis can be predicted with increasing confidence in areas that are instrumented adequately. For example, scientists predicted the 1991 Mt. Pinatubo eruption, based on the increase in seismicity and surface deformation caused by the motion of magma within the volcano, enabling civil leaders to evacuate surrounding areas in time. See C. Newhall, J.W. Handley II, and P.H. Stauffer, "Benefits of Volcano Monitoring Far Outweigh Costs: The Case of Mount Pinatubo," *U.S. Geological Survey Fact Sheet* 115-97, 1997.

Sidebar 1.2 The Tsunami of December 26, 2004

The tragic events following the earthquake and tsunami in South Asia highlight the global need for coordinated disaster preparedness and response. Seismometers detected the earthquake that triggered the tsunami and satellite altimeters detected the tsunami before it struck land (figure below). A tsunami warning system could potentially have saved tens of thousands of lives, but it did not exist in this region. In the aftermath of the disaster, a wide array of high-resolution satellite images and measurements are helping guide and monitor relief and recovery efforts and assisting in the deployment of resources (food, water, and medical supplies). As nations rebuild their devastated communities, Earth observations will provide critical inputs into decisions on the location, land use, and type of disaster-resistant construction practices that will improve human conditions in these disaster-prone regions.[1]



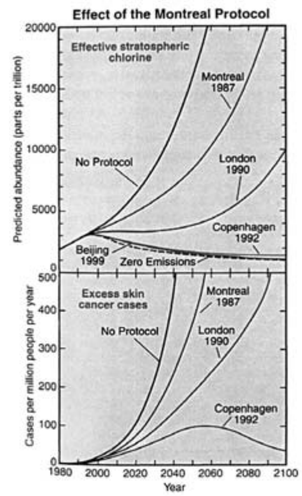
Model of the anomalous water height (warm colors are increases in height and cool colors are decreases in height) caused by the deep-water propagation of the tsunami (top). Bottom figure compares the altimetry data (black line) from the Jason-1 satellite 2 hours after the event with the model result (blue line). SOURCE: NOAA's Pacific Marine Environmental Laboratory.

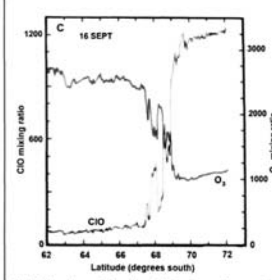
[1] See, for example, the USGS National Map Hazards Data Distribution System (<http://gisdata.usgs.gov/Website/Disaster_Response/viewer.php?Box=30.0:-30.0:120.0:45.0>) and the Cornell University Tsunami reconnaissance relief site for Sri Lanka (<http://polarbear.css.cornell.edu/srilanka/>).

Sidebar 1.3 Human Health, Exposure to Ultraviolet Radiation, and Ozone

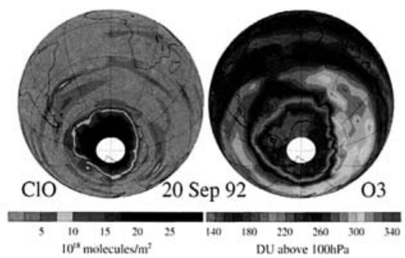
The Earth science and medical science communities have joined forces to understand and predict human morbidity rates resulting from the increasing incidence of skin cancer. Exposure to ultraviolet radiation, which damages DNA, is a risk factor for this cancer. Using satellite and other observations (bottom), Earth scientists have learned how the industrial release of CFCs leads to the dramatic loss of ozone over both the Arctic and the Antarctic. Their studies led to the regulation of an array of synthetic organic chlorine and bromine compounds through the Montreal Protocol and the ensuing London and Copenhagen amendments. A reduction of these compounds is projected to decrease the incidence of skin cancer, other factors being equal (upper right).

SOURCE: Montreal Protocol figure from World Meteorological Organization, *Scientific Assessment of Ozone Depletion: 2002*, WMO Report 47, Geneva, 2003. Ozone-ClO anticorrelation and satellite images of ClO and O_3 are from World Meteorological Organization, *Scientific Assessment of Stratospheric Ozone: 1994*, WMO Report 37, Geneva, 1994.





NASA aircraft in situ ClO-O_3 anti-correlation across Antarctic vortex edge.



NASA microwave LIMB sounder satellite observation of ClO and O_3.

2
Earth Observations and Presidential Initiatives

One of my main concerns . . . is ensuring that the full range of science, including Earth Science, remains a priority at NASA even as we move ahead to return to the moon by 2020. There simply is no planet more important to human beings than our own, and we're remarkably ignorant about it. NASA's Earth Science mission is essential.

House Science Committee Chairman Sherwood Boehlert
speaking to the Consortium for Oceanographic Research and Education
on March 9, 2005.[1]

Three presidential initiatives concern Earth science and applications. Two of the initiatives—the 2001 U.S. Climate Change Research initiative[2] and the 2003 Global Earth Observation initiative[3]—underscore both the traditional U.S. value of pushing back the frontiers of knowledge and the practical importance of obtaining Earth science information to meet national and international objectives. They directly support the need to protect life and property though improved forecasting and to promote economic vitality, while increasing knowledge and understanding about the complex planet on which we live. A third presidential initiative, the 2004 Vision for Space Exploration, looks beyond Earth and establishes new priorities for NASA.[4]

The Climate Change Research Initiative led to the establishment of the national Climate Change Science Program (CCSP).[5] The CCSP encompasses the programs of the U.S. Global Change Research Program, which was itself a presidential initiative of a previous administration. In addition to advancing understanding of the climate system, the CCSP has established three goals to improve the ability to predict and cope with the effects of climate change: (1) reduce uncertainty in projections of how Earth's climate and related systems may change in the future; (2) understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes; and (3) explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change.[6]

The Global Earth Observation initiative led to an Earth Observation Summit, hosted by the United States, in July 2003 in Washington, D.C. Thirty-three nations and the European Commission participated in the summit and affirmed "the need for timely, quality, long-term, global information as a basis for sound decision making."[7] They noted, "In order to monitor continuously the state of the Earth, to increase understanding of dynamic Earth processes, to enhance prediction of the Earth system, and to further implement our environmental treaty obligations, we recognize the need to support improved

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[1] The full text of Rep. Boehlert's speech is available at <http://www.house.gov/science/press/109/109-33.htm>.

[2] See <http://www.climatevision.gov/statements.html>

[3] See <http://www.whitehouse.gov/news/releases/2002/02/20020214-5.html>; <http://www.earthobservationsummit.gov/press_release_whfs.html>.

[4] See <http://www.whitehouse.gov/news/releases/2004/01/20040114-1.html>.

[5] Thirteen federal agencies participate in the program, which is managed by a subcommittee chaired by James Mahoney, NOAA.

[6] The other CCSP goals are to (1) improve knowledge of Earth's past and present climate and environment, including its natural variability, and improve understanding of the causes of observed variability and change and (2) improve quantification of the forces bringing about changes in Earth's climate and related systems. See Climate Change Science Program and Subcommittee on Global Change Research, *Strategic Plan for the U.S. Climate Change Science Program*, Washington, D.C., 202 pp., 2003.

[7] See <http://earthobservations.org/default.asp>. The summit also affirmed the need for (1) a coordinated effort to involve and assist developing countries in improving and sustaining their contributions to observing systems, (2) the timely exchange of observations, and (3) a process for the preparing a 10-year implementation plan. To this end, the summit established the ad hoc Group on Earth Observations.

coordination of strategies and systems for observations of the Earth and identification of measures to minimize data gaps, with a view to moving toward a comprehensive, coordinated, and sustained Earth observation system or systems. . . ." At the second Earth Observation Summit, held in Tokyo in April 2004, the concept of the Global Earth Observing System of Systems (GEOSS) was accepted. Participating governments accepted the draft 10-year plan to implement GEOSS at the third summit, held in Brussels in February 2005.

Finally, the president's Vision for Space Exploration initiative led to a reorganization of NASA and established a new focus on exploration of the Moon, Mars, and solar system. The planning document that accompanied NASA's FY 2006 budget proposal lists five guiding national objectives for NASA, including "study the Earth system from space and develop new space-based and related capabilities for this purpose."[8] However, the priority for Earth observations, which have direct and immediate relevance to society, appears greatly diminished in terms of the projected declining budgets that are proposed for FY 2006. *The committee strongly believes that NASA must retain Earth science as a central priority, to support critical improvements in understanding the planet and developing useful applications.*

Prior to setting a decadal agenda, which is the task of the Committee on Earth Science and Applications from Space and its panels during the next year, it is important to recognize emerging threats to the execution of Earth science research and applications programs. The reallocation of resources within NASA has emerged as a dominant consideration in addressing the decadal agenda. Resources available to Earth observation programs are declining, making it difficult for NASA to fulfill its obligations to the CCSP and GEOSS. A comparison of NASA's proposed FY 2006 budget with previous budgets indicates that at least six Earth observing missions have been canceled, descoped, or delayed. Explorer-class missions—conducted under NASA's Earth System Science Pathfinder program and intended to provide a continuous infusion of new technology and ideas into Earth science programs and to build human capacity for future scientific and technological advances—have been repeatedly delayed.

In addition, the committee is concerned that significant resources for the research and analysis (R&A)[9] programs that sustain the interpretation of Earth science data have been reallocated either as a result of the removal of the "firewall" that previously existed between flight and science programs or as an unintended consequence of NASA's shift to full-cost accounting. Because the R&A programs are carried out largely through the nation's universities, there will be an immediate and deleterious impact on graduate student, postdoctoral, and faculty research support. The long-term consequence will be a diminished ability to attract and retain students interested in using and developing Earth observations. Taken together, these developments jeopardize U.S. leadership in both Earth science and Earth observations, and they undermine the vitality of the government-university-private sector partnership that has made so many contributions to society.

In Chapter 3 the committee makes a number of recommendations to restore the health of the Earth observations and related research and operational effort in the United States and to set the stage for steady advances in Earth science and applications over the next decade.

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[8] National Aeronautics and Space Administration, *The New Age of Exploration: NASA's Direction for 2005 and Beyond*, NP-2005-01-397-HQ, Washington, D.C., 2005, <http://www.nasa.gov/pdf/107490main_FY06_Direction.pdf>.

[9] R&A has customarily supplied funds for enhancing fundamental understanding in a discipline and stimulating the questions from which new scientific investigations flow. R&A studies also enable conversion of raw instrument data into fields of geophysical variables and are an essential component in support of the research required to convert data analyses to trends, processes, and improvements in simulation models. They are likewise necessary for improving calibrations and evaluating the limits of both remote and in situ data. Without adequate R&A, the large and complex task of acquiring, processing, and archiving geophysical data would go for naught. Finally, the next generation of Earth scientists—the graduate students in universities—are often educated by performing research that has originated in R&A efforts. See National Research Council, Earth Observations from Space: *History, Promise, and Reality (Executive Summary)*, The National Academies Press, Washington, D.C., 26 pp., 1995.

3
Critical Needs for Today

U.S. observing systems are undergoing a major transition. NASA's Earth Observation System (EOS) has been launched and is producing an extraordinary array of science, yet almost no new research missions are planned or are in development. The National Polar-orbiting Operational Environmental Satellite System (NPOESS), scheduled for launch in late 2009, will replace polar-orbiting weather satellites flown separately by NOAA and the Department of Defense. It will be preceded by a transitional and risk-reduction mission, the NPOESS Preparatory Program (NPP). And beginning in 2012, NOAA's Geostationary Operational Environmental Satellite (GOES) will be upgraded to improve weather forecasts, hazard monitoring, and atmospheric research.

The decisions behind these transition plans, many of them made during the 1990s, both create and limit the opportunities that are available over the next decade and beyond. For example, the decision to integrate climate observations into NPOESS creates some efficiencies but also significant compromises in instrument capabilities and limitations in the resulting value of the observations for climate applications.

The U.S. government's historic approach of dividing responsibility for Earth observations also constrains what new missions can be flown. Under the current arrangement, NASA is responsible for research missions, NOAA is responsible for operational missions, and the USGS has certain responsibilities for the Landsat missions and for land-based monitoring systems. However, as research and operational applications become more tightly integrated, it will be necessary to reconsider how to manage these functions and accelerate the rate of transition of research results to operational products of use to society.[1]

The ability to capitalize on previous research for both new science and societal applications requires a robust scientific and technological program aimed at making systematic progress in understanding Earth as a system and creating new knowledge and applications. This interim report focuses on actions required within the next year; it is based on the committee's review and analysis of mission plans that were current as of April 2005. The committee did not attempt to evaluate new missions—a task whose results will be presented in the committee's final report in late 2006.

As a result of the recent mission cancellations, budget-induced delays, and mission descopes, the committee finds the existing Earth observing program to be severely deficient. The following near-term recommendations describe the minimum set of actions needed to maintain the health of the NASA scientific and technical programs until more comprehensive community recommendations are made in the final report of the survey. They address deficiencies in the current program at NASA and some of the emerging needs of NOAA and the USGS. The recommendations address issues in five interrelated areas:

1. Canceled, descoped, or delayed Earth observation missions;
2. Prospects for the transfer of capabilities from some canceled or descoped NASA missions to NPOESS;
3. The adequacy of the technological base for future facility-class and smaller missions;
4. The status and future prospects of Earth science Explorer-class missions; and
5. Development of baseline climate observations and data records.

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[1] National Research Council, *Satellite Observations of the Earth's Environment: Accelerating the Transition of Research to Operations*, The National Academies Press, Washington, D.C., 2003.

PROCEED WITH MISSIONS THAT HAVE BEEN CANCELED, DESCOPED, OR DELAYED

Table 3.1 summarizes a number of recent Earth observing missions or mission programs that have been canceled, descoped, or delayed. The instruments on all of these missions have been demonstrated technologically and are ready for near-term launch. All have important societal applications, as discussed below.

The committee's conclusions and recommendations regarding these missions are presented in the sections that follow.

TABLE 3.1 Canceled, Descoped, or Delayed Earth Observation Missions

Mission	Measurement	Societal Benefit	Status
Global Precipitation Measurement	Precipitation	Reduce vulnerability to floods and droughts; manage water resources in arid regions; improve forecasts of hurricanes	Delayed
Atmospheric Soundings from Geostationary Orbit	Temperature and water vapor	Protect life and property through improved weather forecasts and severe storm warnings	Canceled
Ocean Vector Winds	Wind speed and direction near the ocean surface	Improve severe weather warnings to ships at sea; improve crop planning and yields through better predictions of El Niño	Canceled
Landsat Data Continuity	Land cover	Monitor deforestation; find mineral resources; track the conversion of agricultural land to other uses	Canceled
Glory	Optical properties of aerosols; solar irradiance	Improve scientific understanding of factors that force climate change	Canceled
Wide Swath Ocean Altimeter (on the Ocean Surface Topography Mission)	Sea level in two dimensions	Monitor coastal currents, eddies, and tides, all of which affect fisheries, navigation, and ocean climate	Instrument canceled—descope of mission

Global Precipitation Measurement

In spite of steady advances in weather predictions and warnings, society is increasingly vulnerable to costly floods and droughts.[2] Accurate measurement and prediction of precipitation are essential to reduce this vulnerability and improve the management of water resources. Such measurements can be obtained from space-borne active microwave sensing (radar), which provides direct, fine-scale observations of the three-dimensional structure of precipitation systems.

The first spaceborne precipitation radar, on the Tropical Rainfall Measuring Mission (TRMM), was launched in 1997 and provided insights into the microphysical dynamics of the formation of

[2] For instance, the 1988 central U.S. drought is estimated to have cost $40 billion to $60 billion. See information compiled by NOAA's National Climatic Data Center, <http://www.ncdc.noaa.gov/oa/reports/billionz.html>. Global flood losses over the last decade have exceeded $200 billion. Munich Reinsurance Company, *World Map of Natural Hazards*, Munich, Germany, 1998.

precipitation. These measurements led to improved operational forecasts of precipitation and estimates of hurricane storm tracks, which in turn have almost certainly reduced economic losses and saved lives.[3] TRMM has already exceeded its planned lifespan, and a replacement, the Global Precipitation Measurement (GPM) mission, will be built in partnersbip with Japan, Europe, and possibly France and India. GPM will consist of a core satellite with a precipitation radar and an advanced radiometer, accompanied by approximately seven satellites with passive radiometers. The GPM constellation will provide global coverage at 3-hour intervals over most land and ocean areas (latitude 65° S to 65° N).

GPM was originally planned to be launched in 2007, which would have minimized the gap in global precipitation coverage after TRMM ended. However, the current estimated launch date is 2010. The committee is pleased to see that GPM is in NASA's proposed FY 2006 budget but is concerned that the planned launch date has slipped 3 years since initial planning.

The committee recommends that the Global Precipitation Measurement mission be launched without further delays.

Atmospheric Soundings from Geostationary Orbit

Atmospheric soundings of temperature and water vapor are routinely made from polar-orbiting satellites, and they contribute essential observations for weather forecasting. However, the time between soundings from a single polar-orbiting satellite is approximately 12 hours, and this sampling frequency is too low for observing the development of and the rapid changes associated with severe weather, including tornadoes, flash floods, and hurricanes. High-frequency soundings over the United States are being made from geostationary orbit, and there is a plan to upgrade these and other capabilities in 2012 with the launch of the next-generation operational GOES sounder, GOES-R. The Geostationary Imaging Fourier Transform Spectrometer (GIFTS) is a new technology that is designed to obtain 80,000 closely spaced horizontal (~4 kilometers), high-vertical-resolution (~1 kilometer) atmospheric temperature and water vapor soundings every minute from geostationary orbit.[4] The high-vertical-resolution water vapor flux measurements also provide a measure of the winds. These measurements will significantly improve numerical weather prediction and severe weather warnings.

The components of GIFTS have been developed, with more than $100 million of prior NASA support,[5] and are being assembled as a prototype for GOES-R risk reduction. However, facing budget problems that were partly the result of the Navy's withdrawal of its planned supply of a launch vehicle, NASA discontinued funding for the GIFTS project beyond FY 2005. The result was a shortfall in funds needed to complete the fabrication and testing of the GIFTS instrument. NOAA provided additional financial support to complete integration of the components of GIFTS and carry out thermal vacuum tests, which will be completed later this year. But no funds have been identified to finish the space qualification of GIFTS, and a space mission opportunity has not yet been secured. A World Meteorological Organization (WMO)-led international effort (International Geostationary Laboratory, IGeoLab)[6] is getting underway to test GIFTS in space. The plan is to position GIFTS over different regions of Earth to demonstrate the global value of the observations and to prepare the international

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[3] Although TRMM data contribute to El Niño predictions, the socioeconomic effects of TRMM-improved forecasts have not yet been quantified. See National Research Council, *Assessment of the Benefits of Extending the Tropical Rainfall Measuring Mission: A Perspective from the Research and Operations Communities, Interim Report*, National Academies Press, Washington, D.C., 2004.

[4] See <http://cimss.ssec.wisc.edu/itwg/itsc/itsc13/proceedings/session7/7_1_lemarshall.pdf>.

[5] Personal communication, R. Reisse, NASA GIFTS project manager, March 8, 2005.

[6] See <http://www.eumetsat.int/en/area2/cgms/cgms_xxxii/CGMS-XXXII_Working_Papers/CGMS-XXXII_EUM_WPs/CGMS-XXXII_EUM_WP_18.pdf>.

community for the use of similar data from future operational geostationary satellites. This test could occur as early as 2008, providing 4 years of useful data before the launch of GOES-R.

The committee recommends that NASA and NOAA complete the fabrication, testing, and space qualification of the GIFTS instrument and that they support the international effort to launch GIFTS by 2008.

EVALUATE PLANS FOR TRANSFERRING NEEDED CAPABILITIES TO NPOESS

Instruments on three canceled missions may either be transferred from NASA or replaced with other instruments for flight on NPOESS. These instruments would provide a capability to measure ocean vector winds, land surface changes, aerosol properties, and solar irradiance. Transferring these capabilities from independent NASA missions to NPOESS brings advantages (e.g., transfer of research capabilities to operational use) and disadvantages (e.g., decreased instrument capability, data gaps), as discussed below.

Ocean Vector Winds

Measurements of wind speed and direction near the ocean surface (ocean winds) by satellite observation systems are crucial for monitoring the motion of the atmosphere and oceans and their interaction.[7] In particular, accurate knowledge of ocean winds is vital to studies of air-sea interactions,[8] ocean circulations, and El Niño forecasts.[9] Accurate ocean winds also improve weather forecasts and storm warnings. The use of QuikSCAT wind data, for example, improved National Weather Service forecasts of the four hurricanes that devastated the southeast United States in 2004 and marine warnings to ships at sea.[10] Furthermore, by improving the ability to anticipate how climate and weather will change from one season or year to the next, ocean winds can help us to better manage global agriculture, water reserves, and other resources.

Microwave scatterometers have been flown by NASA and the European Space Agency since 1991, and ocean wind data have been assimilated into weather forecast systems for several years. The current scatterometer—SeaWinds—was launched in 1999 on NASA's QuikSCAT satellite as a "quick recovery" mission intended to fill the data gap when the satellite hosting the NASA Scatterometer (NSCAT) lost power in June 1997. QuikSCAT has already exceeded its planned 3-year lifetime, but the follow-on NASA mission (Ocean Vector Winds Mission), originally scheduled for launch in 2008, has been canceled by NASA.

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[7] Although instruments on buoys and ships provide measurements of surface wind vectors, their coverage is insufficient to provide a global wind map. In contrast, satellite-based sensors can provide near-global coverage in one day. Moreover, QuikSCAT ocean winds have proven to be highly accurate. See Freilich, M.H., and R.S. Dunbar, The accuracy of the NSCAT 1 vector winds: Comparisons with National Data Buoy Center buoys, *J. Geophys. Res.* 104(C5): 11,231, 1999.

[8] For example, ocean wind data will support an NSF-sponsored field program (CLIvar MOde water Dynamics Experiment) to study the details of air-sea interaction and improve climate models.

[9] In an El Niño year, changes in wind and ocean circulation alter typical rainfall patterns and result in the release of large amounts of heat into the atmosphere. The subsequent energy propagates within the atmosphere, affecting the weather in various ways and places and disrupting the normal rhythm of life across the Pacific Ocean. The ability to accurately predict El Niño is of great benefit to the United States and to countries around the world.

[10] February 8-10, 2005, NASA/NOAA workshop, "Satellite Measurements of Ocean Vector Winds: Present Capabilities and Future Trends," Florida International University, Miami, Florida, <http://cioss.coas.oregonstate.edu/CIOSS/workshops/miami_meeting/Agenda.html>. A forecaster from NCEP's Tropical Prediction Center stated that "without QuikSCAT they would be forecasting in the dark."

Both active (radar) and passive (radiometer) microwave sensors are capable of determining ocean surface wind speed, and active microwave instruments are also used to derive the wind direction. The European Space Agency plans to launch an active scatterometer instrument (the Advanced Scatterometer, ASCAT) on its MetOp-1 satellite in late 2005.[11] However, it has only about half of the coverage of QuikSCAT (two narrower bands with a gap in the middle). Moreover, significant improvements to weather forecasts require more than one instrument because of the large space between swaths.[12]

A passive microwave sensor (Windsat) has been launched to test the technology for the Conical Scanning Microwave Imager/Sounder (CMIS) instrument, which will be launched on the first NPOESS.[13] Preliminary analysis suggests that such passive systems will produce wind observations with less accuracy and with more contamination by rain and land than active scatterometers.[14] As a result, the substitution of passive microwave sensor data for scatterometry data would worsen El Niño and hurricane forecasts and weather forecasts in coastal areas.[15]

Landsat Data Continuity

Landsat has provided the longest and best-calibrated time series of information about changes in land cover and land use for over 30 years. Today, however, the continuity of this data record is at risk. Despite the varied ongoing uses of Landsat data, the program has not been put on a truly operational basis. The current mission—Landsat 7—is operating in a diminished capacity,[16] long after its original design life has been exceeded, and NASA has canceled a Landsat continuity mission.[17]

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[11] See <http://www.esa.int/export/esaME/ascat.html>.

[12] Presentation by R. Knabb, C. Hennon, D. Brown, J. Franklin, H. Cobb, J. Rhome, and R. Molleta, Impact of QuikSCAT on Tropical Prediction Center operations, NASA/NOAA workshop, Miami, Fla., February 8-10, 2005.

[13] Windsat was built by the Naval Research Laboratory, with cooperation from NASA, the Air Force, and the NPOESS Integrated Program Office.

[14] Freilich, M.H., and B.A. Vanhoff, The accuracy of preliminary Windsat vector wind measurements: Comparisons with NDBC buoys and QuikSCAT, *IEEE Trans. Geosci. Rem. Sensing*, in press, 2006.

[15] The passive system does not provide useful wind direction for winds of 5 meters per second or less (scatterometer threshold is 2 meters per second). Moreover, wind direction errors for winds 6-8 meters per second (the wind speed range which forces ENSO events) will be double that of the scatterometer. The median global wind speed is about 7 meters per second, which suggests that a passive system will not provide reliable directions for half of the winds. In addition, rain and land contamination of wind vectors from a passive system will be greater than from a scatterometer, which limit their use in forecasts of hurricanes and weather in coastal regions. WindSAT is comparable in quality to QuikSCAT for wind speeds greater than 8 meters per second, in the absence of rain. However, forecasters at a recent workshop noted that even the relatively small dropout rate of QuikSCAT data from rain was a concern. See presentations at a NASA/NOAA workshop, Satellite Measurements of Ocean Vector Winds: Present Capabilities and Future Trends, Miami, Fla., February 8-10, 2005, <http://cioss.coas.oregonstate.edu/CIOSS/workshops/miami_meeting/Agenda.html>.

[16] In June 2003 a failure of the scan line connector (SLC) diminished the capability of the ETM+ (Enhanced Thematic Mapper, plus) instrument. For a description of the problem, see <http://landsat.usgs.gov/pdf/2003junelmu.pdf>. Without the SLC, the sensor still provides coverage of approximately 78 percent of each scene. However, the temporal repeat frequency of coverage has been severely affected and now takes two or more acquisitions to produce one complete view.

[17] The White House Office of Science and Technology Policy called for a study on a bridging mission to fill the gap between Landsat 7 and NPOESS, planned for launch in December 2009. A memorandum from the Office of Science and Technology Policy (OSTP), signed on August 13, 2004, by the Director of OSTP, Dr. John Marburger, III, states that "the Departments of Defense, the Interior, and Commerce and the National Aeronautics and Space Administration have agreed to take the following actions: (1)Transition Landsat measurements to an operational environment through the incorporation of Landsat-type sensors on the National Polar-orbiting Operational Environmental Satellite System (NPOESS) platform; (2) Plan to incorporate a Landsat imager on the first NPOESS spacecraft (known as C-1), currently scheduled for launch in late 2009; (3) Further assess options to mitigate the

The plan outlined in the president's FY 2006 budget is to have NASA provide an Operational Land Imager (OLI) for flight on the first NPOESS platform. This decision increases the likelihood that critical land cover measurements will be sustained during the NPOESS era. However, since the scan line connector malfunctioned in 2003, Landsat 7 has not been able to achieve the goal of refreshing the global data set seasonally. Consequently, a significant data gap in the Landsat record is already occurring. Actions proposed in NASA's FY 2006 plan will further increase this data gap, and the gap will obviously be considerably longer if the NPOESS launch date is delayed.

The gap cannot be completely filled by land surface data collected by commercial and foreign sources. Each of these alternative sources has disadvantages, including the high cost of purchasing data or reprogramming algorithms to analyze the data, lack of calibration, and limited geographic coverage. Moreover, the proposed use of the large NPOESS platform to acquire Landsat-type imagery raises technical concerns, including the demands of the imager on the volume and throughput of data systems, and the influence of the jitter of a large platform on the image quality.

Aerosols and Total Irradiance Monitor—Glory

The Glory mission,[18] which was to fly the Advanced Polarimetric Sensor (APS) to measure optical properties of aerosols and the Total Irradiance Monitor (TIM) to measure solar irradiance, is slated for cancellation. The Glory mission would provide data essential for climate research and prediction—it would yield the first global aerosol measurements with composition specificity and precise microphysical data on both aerosols and cloud particles needed to infer direct and indirect aerosol climate forcings. It also would ensure continuity of the solar irradiance time series, which goes back to 1978 and whose value would be diminished should there be any gap in the measurement.[19]

The cancellation of the Glory mission is especially worrisome because just last year, at the January 2004 meeting of the American Meteorological Society, NASA Administrator Sean O'Keefe called for accelerating the flight of the Glory mission to meet NASA's commitment to the CCSP.[20] To go from acceleration to cancellation in 1 year may reflect programmatic and other difficulties for Earth sciences at NASA in general. However, the cancellation has also had impacts on the NPOESS program.

The APS had originally been scheduled to fly on NPOESS in 2010, but when NASA chose its own procurement path for the APS instrument on Glory, the Integrated Program Office for NPOESS

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risks to data continuity prior to the first NPOESS-Landsat mission, including a 'bridge' mission." The OSTP memorandum can be found at the NASA LDCM web site at <http://ldcm.nasa.gov>.

[18] See <http://www.esa.ssc.nasa.gov/m2m/mission_report.aspx?mission_id=233>.

[19] Six overlapping satellite experiments have monitored TSI since late 1978: (1) NOAA's Nimbus-7 Earth Radiation Budget (ERB) experiment (1978-1993), (2) NASA's Active Cavity Radiometer Irradiance Monitor (ACRIM) 1 on the Solar Maximum Mission (1980-1989), (3) NASA's Earth Radiation Budget Experiment on the Earth Radiation Budget Satellite (ERBS) (3 missions, running from 1984 to today), (4) NASA's ACRIM2 on the Upper Atmosphere Research Satellite (1991-2001), (5) NASA's ACRIM3 on the ACRIMSAT satellite (2000 to present). The European Space Agency's SOHO/VIRGO experiment also provided an independent data set during 1996-1998.

[20] O'Keefe noted, "Nearly three years ago the President announced a significant Climate Change Research Initiative that now engages the talents of several federal agencies, including NASA. The Administration's decadal strategic plan for Climate Change Science calls for three major areas of emphasis to accelerate the availability of the scientific information and models needed to help inform policy decisions. The first area of emphasis is on the emerging science of non-CO_2 greenhouse gas forcing, especially aerosols; carbon over North America; and climate feedbacks involving clouds, water vapor, and Polar Regions. . . . As part of NASA's commitment to the Climate Change science program, we hope to accelerate the flight of the Glory mission to as early as 2007 to provide earlier availability of this space-based polarimeter that measures the optical properties of aerosols and clouds. This device is slated to become a regular part of the next generation military and civilian weather satellite system." Remarks given by Sean O'Keefe, American Meteorological Society, Seattle, Washington, on January 11, 2004. See <http://www.nasa.gov/audience/formedia/speeches/ok_meteorological_society_011104.html>.

significantly delayed its procurement plans for APS. As a consequence, if the APS procurement is reinstated into NOAA plans, the instrument will not be available to fly until 2012 at the earliest. However, the APS and TIM instruments could fly on the first NPOESS mission if NASA builds them and pays for their integration costs.

This record of start then stop, of acceleration then delay, and of canceling important missions without notice is at odds with NASA's stated science goals and commitment to the CCSP. Moreover, decisions to transfer capabilities from NASA to NOAA were not always made after an appropriate study of the advantages and disadvantages of an NPOESS solution, or with adequate consultation with the scientific and user community. The committee recognizes that there are substantial competing demands on NASA's budget and that additional funds will be needed to fully address the recommendations in this report.

The committee recommends that NASA and NOAA commission three independent reviews, to be completed by October 2005, regarding the Ocean Vector Winds, Landsat Data Continuity, and Glory missions. The reviews should evaluate:

- **The suitability, capability, and timeliness of the OLI and CMIS instruments to meet the research and operational needs of users, particularly those that have relied on data from Landsat and QuikSCAT;**
- **The suitability, capability, and timeliness of the APS and TIM instruments for meeting the needs of the scientific and operational communities;**
- **The costs and benefits of launching the Landsat Data Continuity and Glory missions prior to and/or independently from the launch of the first NPOESS; and**
- **The costs and benefits of launching the Ocean Vector Winds mission prior to or independently of the launch of CMIS on NPOESS.**

If the benefits of an independent NASA mission(s) cannot be achieved within reasonable costs and risks, the committee recommends that NASA build the OLI (two copies, one for flight on the first NPOESS platform[21]), APS, and TIM instruments and contribute to the costs of integrating them into NPOESS. APS, TIM, and the first copy of OLI should be integrated onto the first NPOESS platform to minimize data gaps and achieve maximum utility.

The reviews could be conducted under the auspices of NASA and NOAA external advisory committees or other independent advisory groups and should be carried out by representative scientific and operational users of the data, along with NOAA and NASA technical experts.

DEVELOP A TECHNOLOGY BASE FOR FUTURE EARTH OBSERVATION

NASA's Earth Observing System was intended to serve as the foundation for its long-term efforts in Earth science and applications. EOS involves a number of instruments and platforms, a community of world-class scientists, and the infrastructure to consolidate data and information from surface campaigns and remote sensing satellites. The centerpiece of the system is a set of three spacecraft with multiple instruments for studying processes over land, oceans, and atmosphere—EOS Terra, Aqua, and Aura, respectively. Initial plans made in the 1980s called for development of three series of each of these satellites. Launched every 18 to 24 months and with replacements every 5 years, NASA hoped to ensure at least a 15-year record of continuous measurements to address the highest-priority science and policy questions, as identified by the interagency Committee on Earth and Environmental Sciences and the Intergovernmental Panel on Climate Change (IPCC).

[21] The Landsat Data Continuity mission called for the procurement of two instruments, each with a mission lifetime of 5 years, to provide continuity to the Landsat 7 data set.

NASA has changed plans for the EOS series so that now there will be no follow-on spacecraft launched as the second or third elements of Terra, Aqua, or Aura. The development of the longer-term records rests now on the NPOESS, GOES-R, and foreign missions. Aside from selected (and delayed) ESSP missions, the descoped Ocean Surface Topography mission (Jason-2), and the Global Precipitation Measurement mission, the NASA program for the future has no explicit set of Earth observation mission plans. Moreover, there is no corresponding research and analysis program for NPOESS as there was for EOS.

Given the long lead times (up to a decade)[22] required to identify user needs and develop instrument capabilities, it is essential to have a prioritized science mission strategy based on societal needs and opportunities. Although the ESSP process is resulting in a new mission every 3 years, this process is completely inadequate to meet established needs. Indeed, ESSP was initially conceived as a means to augment the existing EOS line with smaller, more rapid, and technologically flexible missions. Soon there will be little to augment, and the ESSP is, itself, stretched out and delayed.

The absence of a robust set of out-year science missions in active development and in a planning queue is troubling because a number of societally important and scientifically compelling mission concepts are ready to be implemented. Further, the absence of out-year missions will likely result in a stagnant technology base.

The committee's final report will include a prioritized list of Earth observation missions and activities. This interim report does not preview those recommendations, but the committee can foresee needed technologies for missions that have been under discussion for several years. Three examples with great societal relevance are interferometric synthetic aperture radar, wide-swath ocean altimetry, and measurement of tropospheric winds from space.

Interferometric synthetic aperture radar (InSAR) has demonstrated the capability to make fundamental contributions to understanding the processes that cause earthquakes, volcanic eruptions, and landslides.[23] However, existing InSAR satellites, which are being flown by the Canadian and European space agencies, have serious limitations:

- The radars collect data in the C-band, which does not work well in vegetated areas; and
- Demand is so high that images are available only for limited areas and at limited times.

Even without these limitations, continued information from these satellites is problematical as they have reached the end of their useful lifetimes.

The shortage of InSAR images will also limit the success of EarthScope, a multi-agency program to explore the three-dimensional structure of the North American continent,[24] and efforts to monitor earthquake and volcano hazards around the world. For these reasons, an InSAR mission has emerged as the top priority for the solid-Earth community.[25] Investments in the technological base for the L-band are needed to move forward on this mission.

To map the sea-surface height in two dimensions with satisfactory resolution, a new type of radar

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[22] For large observational programs such as NPOESS, the time from concept to launch can take the better part of a decade. In contrast, some of the smaller, cheaper, and less complex Explorer-class programs can be executed in less than 4 years. A good example of this possibility of rapid execution is the recently awarded Interstellar Boundary Experiment (IBEX), which will be launched in 2008; however, not all examples are so positive. The ESSP mission Hydros was selected in 2002, but it will not be launched in late 2010.

[23] InSAR measurements of strain over wide geographic areas would also complement the continuous GPS point measurements being taken collected along the western edge of the United States, Mexico, and Canada through the Plate Boundary Observatory component of the NSF EarthScope initiative.

[24] National Research Council, *Review of EarthScope Integrated Science*, National Academies Press, Washington, D.C., 2001.

[25] National Aeronautics and Space Administration, *Living on a Restless Planet*, Solid Earth Science Working Group Report, Pasadena, Calif., 2002, <http://solidearth.jpl.nasa.gov/seswg.html>; National Research Council, *Review of NASA's Solid-Earth Science Strategy*, National Academies Press, Washington, D.C., 2004.

instrument using the principle of radar interferometry has been developed at the Jet Propulsion Laboratory (JPL). JPL's wide-swath ocean altimeter has the potential to provide ocean topography over a 200-kilometer-wide swath, providing a two-dimensional image of sea-surface height, rather than a one-dimensional profile. The wide-swath ocean altimeter was being planned for flight on the international Ocean Surface Topography Mission (Jason-2), but was eliminated because of budgetary reasons. This exciting capability enables measurement of small-scale but important phenomena, such as vortices inside ocean currents, which are needed to improve ocean circulation models and to support marine transportation and fisheries research and forecasts.

Global observations of wind fields in the troposphere are critical for improving weather forecasts, forecasting the trajectory of atmospheric pollutants and pathogens, and better understanding the dynamics of the atmosphere.[26] Many instrument and mission designs have been proposed or developed to measure the global wind field using active remote sensing techniques. In 2007, the European Space Agency will launch its Earth Explorer Atmospheric Dynamics mission (ADM-Aeolus)[27] to measure winds in the troposphere using an ultraviolet laser. The United States has struggled for years to develop a similar capability using lidar techniques.[28]

The committee recommends that NASA significantly expand existing technology development programs to ensure that new enabling technologies for new observational capabilities, including interferometric synthetic aperture radar, wide-swath ocean altimetry, and wind lidar, are available to support potential mission starts over the coming decade.

REINVIGORATE THE NASA EARTH EXPLORER MISSIONS PROGRAM

Satisfying tomorrow's critical societal needs requires us to do exploratory basic science today. In the 1990s, NASA introduced an innovative science mission program called Earth Explorers to do just that. The scientific community has been deeply engaged in planning the Earth System Science Pathfinder (ESSP) missions that fall within the Earth Explorer program. NASA developed its ESSP program as "an innovative approach for addressing Global Change Research by providing periodic 'Windows of Opportunity' to accommodate new scientific priorities and infuse new scientific participation into the Earth Science Enterprise. The program is characterized by relatively low to moderate cost, small to medium sized missions that are capable of being built, tested and launched in a short time interval."[29] ESSP missions were intended to be launched at a rate of one or more per year.[30] Today, Earth Explorers are being delayed, and there is no comparable program targeted to generate new science.

[26] Atlas, R.M., Atmospheric observations and experiments to assess their usefulness in data assimilation, *J. Meteorol. Soc. Jpn.*, 75, 111-130, 1997; Baker, W.E., G.D. Emmitt, F. Robertson, R.M. Atlas, J.E. Molinari, D.A. Bowdle, J. Paegle, R.M. Hardesty, R.T. Menzies, T.N. Krishnamurti, R.A. Brown, M.J. Post, J.R. Anderson, A.C. Lorenc, and J. McElroy, LIDAR-measured winds from space: a key component for weather and climate prediction, *Bull. Am. Meteorol. Soc.*, 79, 581-599, 1998.

[27] See http://www.skyrocket.de/space/doc_sdat/adm-aeolus.htm.

[28] See, for example, SPAce Readiness Coherent Lidar Experiment (SPARCLE), on the world-wide-web at < http://www.ghcc.msfc.nasa.gov/sparcle/sparcle.html.> Also see presentation to NASA by Kavaya et. al., "A New NASA Technology Program for Risk Reduction of Space-Based Lidar Missions," January 24, 2002. Available on the world-wide-web at: <http://space.hsv.usra.edu/LWG/Jan02/Papers.jan02/Kavaya2.jan02.pdf>.

[29] Earth System Science Pathfinder at http://earth.nasa.gov/essp/.

[30] This approach corresponds to the original intent of the Earth System Science Pathfinder program, which solicited proposals every 2 years for satellite measurements that were outside the scope of approved Earth science missions. Proposals were solicited in all Earth science disciplines, from which two missions and one alternate were selected based on scientific priority and technical readiness.

Explorer-class missions are intended to provide more frequent access to space and to allow for experimentation with new technologies.[31] By accepting a higher risk of failure, Explorer-class missions can be developed faster and at lower cost. Although some missions may fail, the net result will be the collection of new or unique scientific data that could not be collected by medium- and large-class missions alone. In addition, an instrument incubator program and related technology development programs foster the development of new technologies that will be used in future ESSP missions.[32] As a result, ESSP missions provide an impetus for advancing longer-term spaceborne measurement programs. At the same time, these smaller missions provide opportunities to train and maintain personnel needed for future missions.[33]

Seven missions have been selected since the ESSP program was initiated in the mid 1990s. Of these, one is collecting data, one (the Vegetation Canopy Lidar mission) was dropped due to concerns about technological readiness, and five are scheduled for launch. The active and planned missions are described in Sidebar 3.1. All of these missions will provide global observations that are difficult or impossible to collect using in situ technologies and that will address gaps in scientific understanding of the Earth system. Many will yield data that will help to reduce uncertainties in the understanding of the climate system, in direct support of the U.S. Climate Change Science Program. In addition, missions including CloudSat and CALIPSO are poised to make significant contributions to the reduction of risk from natural hazards.

Despite the clear successes of the ESSP missions to date and the numerous benefits of the program in terms of technology development, fostering exploratory research, and training new generations of remote sensing scientists, NASA has delayed releasing the announcement of opportunity for the next generation of ESSP missions.[34] The committee views this delay with great concern. The committee is also concerned that all of the ESSP-3 missions (OCO, Aquarius, and Hydros) have been delayed, apparently because of inadequate funding, and the latter two now have exceedingly long development times, particularly given their relatively small size and budget.

The committee supports continuation of a line of Explorer-class missions directed toward advancing the understanding of Earth and developing new technologies and observational capabilities, and urges NASA to:

- **Increase the frequency of Explorer selection opportunities and accelerate the ESSP-3 missions by providing sufficient funding for at least one launch per year, and**
- **Release an ESSP-4 announcement of opportunity in FY 2005.**

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[31] National Research Council, *Steps to Facilitate Principal-Investigator-Led Earth Science Missions*, National Academies Press, Washington, D.C., 2004. NASA science missions can be classified into three general categories: exploratory or explorer class (e.g., existing Earth System Science Pathfinder missions), medium class (e.g., TRMM), and large missions (e.g., EOS Terra platform). Explorer class missions were part of NASA's Space Science Directorate, but their objectives are very similar to the Earth Science Directorate's ESSP program.

[32] National Research Council, *The Role of Small Satellites in NASA and NOAA Earth Observation Programs*, National Academy Press, Washington, D.C., 2000.

[33] National Research Council, *Steps to Facilitate Principal-Investigator-Led Earth Science Missions*, National Academies Press, Washington, D.C., 2004.

[34] According to the NASA ESSP web site <http://earth.nasa.gov/essp/>, a draft announcement of opportunity was expected in the summer of 2004; this site now states that the announcement will not be out before December 2004. The announcement had not been made when this report went to press (March 2005).

Sidebar 3.1 ESSP Missions

The **Gravity Recovery and Climate Experiment (GRACE)** was proposed as part of ESSP-1 in 1996 and selected for implementation in 1997. GRACE was launched successfully in 2002. It consists of two identical spacecraft that are measuring gravity changes that are 100 to 100,000 times smaller than those measured previously, which occur over weeks compared to years, and in spans of 100 miles versus 500 miles. The mission can sense changes in gravity caused by a deep ocean current shifting or an ice sheet melting in Antarctica. It has also provided the first information about variations in groundwater storage at continental scales, an understanding that may help future missions with more advanced technology focus on global groundwater resources.

CloudSat and **CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations)** were proposed as part of ESSP-2 in 1998 and were confirmed by NASA HQ and approved to proceed with implementation in December 2000. They are now scheduled for launch no earlier than July 31, 2005, and for scheduling reasons are more likely to be launched in September 2005.[a] CloudSat will be flown in formation with CALIPSO, which will measure cloud and aerosol composition. These satellites, together with instruments onboard the Aqua platform, will furnish data needed to evaluate and improve the way clouds are parameterized in global models, thereby contributing to better predictions of clouds and thus to the poorly understood cloud-climate feedback problem.

The **Orbiting Carbon Observatory (OCO)** was proposed as part of ESSP-3 in 2001 and selected for implementation in 2002. OCO will undergo a confirmation review at the end of April 2005 and is currently scheduled for launch in September 2008. Instruments on OCO will measure global concentrations of atmospheric CO_2, which can be used to help unravel uncertainties about the fate of global carbon emissions and their ultimate effects on climate.

Aquarius was proposed as part of ESSP-3 in 2001 and selected for implementation in July 2002. It is now scheduled for mission confirmation review in September 2005 and launch in March 2009.[b] Aquarius will measure ocean surface salinity, a key variable that affects ocean circulation and from which patterns of freshwater influxes (via precipitation, river runoff, and melting of ice) and evaporation can be estimated.

Hydros was proposed as part of ESSP-3 in 2001, selected as an alternate mission in 2002, and selected for implementation in December 2003.[b] Mission confirmation review for Hydros is planned for September 2007 and launch is now scheduled for September 2010.[b] Hydros will measure near-surface soil moisture, a key land surface variable that drives evapotranspiration, and hence recycling of moisture to the atmosphere. Soil moisture is also an important determinant of flood susceptibility, and can be used as a drought indicator.

[a] Deborah Vane, Jet Propulsion Laboratory, personal communication on April 5, 2005.
[b] Gary Lagerloef, Earth & Space Research, personal communication on April 22, 2005.

STRENGTHEN BASELINE CLIMATE OBSERVATIONS AND CLIMATE DATA RECORDS

Baseline Climate Observations

Considerations of Earth's variable and changing climate increasingly affect government and business decisions that have large financial consequences. These decisions cannot be made wisely without accurate knowledge of the climate today and how it is changing, or without the capability to predict what it will be in the future. Current and planned observing systems are inadequate for this task.

The committee is pleased that a critical near-term objective for both GEOSS and the CCSP is to establish baseline observations from which to describe climate variability and change.[35] Such baseline observations provide a means of monitoring climate change and testing climate models and forecasts. Two examples demonstrate the importance of long-term, accurate measurements of key observables: (1) the trend of CO_2 concentrations measured at Mauna Loa by Charles Keeling and associates since 1958, and (2) the observation of surface and atmospheric mean temperature, which is based on various instrument records (Figure 3.2). Both records show that trends in global indicators are far more informative and compelling than single values. However, the uncertainty associated with the two trends is vastly different. The CO_2 record is tied to absolute standards, open to the scientific community for scrutiny, and incontrovertible. Virtually all scientists agree that carbon dioxide in the atmosphere has been increasing over this period to the accuracy reported in the Keeling record. In contrast, the temperature record contains significant uncertainty, and there have been serious questions in the scientific community over the past two decades about (1) how much and where the global atmosphere is warming and (2) whether that record can distinguish between different model projections of climate change.[36]

The answers to such questions have significant policy implications. For example, a doubling of CO_2 is forecast to increase global average temperatures by 1.5 to 5°C, but to increase regional temperatures over populated continental zones of the mid-to-high latitudes of the Northern Hemisphere by 4 to 10°C.[37] These changes are, by any measure, rapid and important to people, societies, and the environment, and they underscore the need for decision support tools based on a foundation of tested and trusted baseline global climate observations and on credible long-term climate forecasts.

The design of climate observing and monitoring systems must ensure the establishment of global long-term climate records that are of high accuracy and precision,[38] tested for systematic errors on-orbit, and tied to irrefutable absolute standards by independent methods. It is essential that the accuracy of the

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[35] Climate Change Science Program and Subcommittee on Global Change Research, *Our Changing Planet: The U.S. Climate Change Science Program for Fiscal Years 2004 and 2005*, 2004, <http://www.usgcrp.gov/usgcrp/Library/ocp2004-5/ocp2004-5.pdf>; Ad-hoc Group on Earth Observations, *Global Earth Observing System of Systems: 10-Year Implementation Plan Reference Document*, GEO204, ESA Publications Division, The Netherlands, 2005, <http://earthobservations.org/docs/GEO204%20Final%20Draft%20Reference%20Document.pdf>.

[36] National Research Council, *Improving the Effectiveness of U.S. Climate Modeling*, National Academy Press, Washington, D.C., 2001; Climate Change Science Program and Subcommittee on Global Change Research, *Strategic Plan for the U.S. Climate Change Science Program*, Washington, D.C., 2003; National Research Council, *Implementing Climate and Global Change Research: A Review of the Final U.S. Climate Change Science Program Strategic Plan*, National Academies Press, Washington, D.C., 2004.

[37] Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis*, Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, 2001.

[38] It is important to distinguish between accuracy and precision. Accuracy is the measure of the non-random, systematic error, or bias, that defines the offset between the measured value and the true value as referenced to the absolute standard defined at the National Institute of Standards and Technology (NIST). Precision, on the other hand, is the measure of repeatability without reference to an international standard. Long-term records built upon precision (or stability, reproducibility, repeatability, consistency, continuity, data record overlap, etc.) rely upon efforts to reconcile time or instrument dependent biases without an international standard. They are thereby compromised by lack of continuity in the data record and are open to criticism.

benchmark observations enable the climate record archived today to be verified by future generations in any country. Finally, to meet societal objectives, the long-term record must not be susceptible to compromise by interruptions.

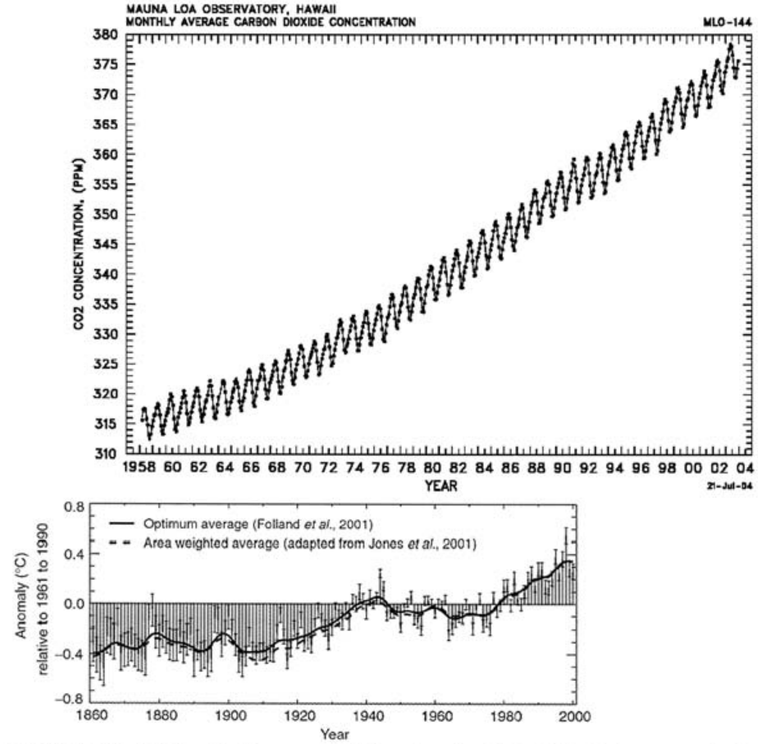

FIGURE 3.2 (Top) Carbon dioxide measured at Mauna Loa since 1958. This is the longest record of carbon dioxide measurements. SOURCE: C.D. Keeling and T.P. Whorf, “Atmospheric CO_2 Records from Sites in the SIO Air Sampling Network,” in *Trends: A Compendium of Data on Global Change,* Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., 2004. (Bottom) Annual global land-surface air and sea surface temperature anomalies (°C), 1861 to 2000, relative to 1961 to 1990. Solid curve is the optimally averaged anomalies from Folland et al., 2001, and the dashed curve is the standard area weighted anomalies (adapted from Jones et al., 2001). Unsmoothed optimum averages appear as red bars, and twice their standard errors are denoted by black “I”. SOURCE: Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis,* Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, 2001.

A full complement of baseline observations will be addressed by the committee in its final report; here the committee indicates some of the high-priority global climate benchmark observations from space:

- *Atmospheric water vapor and temperature* measured globally from the surface to the mid stratosphere with high vertical resolution tied to absolute international standards constitute the foundation of climate records.[39] High-vertical-resolution (0.2 kilometer) temperature to an accuracy of 0.1 K in the lower stratosphere and upper troposphere, and temperature and water vapor in the middle and lower troposphere with unbiased global coverage in all weather can be obtained using the GPS radio occultation technique.[40]
- *Absolute spectrally resolved infrared radiance* emitted from Earth to space measured to high accuracy (0.1 K) against NIST standards on-orbit provides an absolute climate record that separates radiative forcing from the response of the atmosphere with respect to temperature, water vapor, and cloud structure.[41]
- *Absolute incident and reflected solar irradiances* define solar forcing, which constitutes the fundamental long-term record of net energy received by the Earth system. Benchmark observations of total solar irradiance and spectrally resolved solar irradiance to an accuracy of 0.03 percent referenced to NIST standards are required to elucidate the origin of climate change. The incident component ties solar output to an absolute scale,[42] and the reflected component defines the quantitative impact of spatially resolved changes in snow cover, sea ice, aerosol properties, and land use on the flux of energy returned to space.[43]

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[39] National Research Council, *Radiative Forcing of Climate Change: Expanding the Concept and Addressing Uncertainties*, National Academies Press, Washington, D.C., pp. 6 and 111, 2005; Climate Change Science Program, *Strategic Plan for the U.S. Climate Change Science Program*. U.S. Climate Change Science Program, Washington, D.C., p. 127, 2003; National Institute of Standards and Technology, *Satellite Instrument Calibration for Measuring Global Climate Change*, G. Ohring, B. Wielicki, R. Spencer, B. Emery, and R. Datla, eds., Report of a Workshop at the University of Maryland Inn and Conference Center, College Park, Maryland, November 12-14, 2002, NISTIR 7047, Washington, D.C., 2002.

[40] The World Meteorological Organization (WMO) has recommended an operational constellation of radio-occultation satellites as part of the Global Climate Observing System (GCOS). See WMO Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC, GCOS-92 (WMO/TD No. 1219), Geneva, Switzerland, 2004.

[41] National Research Council, *Radiative Forcing of Climate Change: Expanding the Concept and Addressing Uncertainties*, National Academies Press, Washington, D.C., pp. 6 and 111, 2005; Climate Change Science Program, *Strategic Plan for the U.S. Climate Change Science Program*. U.S. Climate Change Science Program, Washington, D.C., p. 127, 2003; National Institute of Standards and Technology, *Satellite Instrument Calibration for Measuring Global Climate Change*, G. Ohring, B. Wielicki, R. Spencer, B. Emery, and R. Datla, eds., Report of a Workshop at the University of Maryland Inn and Conference Center, College Park, Maryland, November 12-14, 2002, NISTIR 7047, Washington, D.C., 2002.; Pollock, D.B., T.L. Murdock, R.U. Datla, and A. Thompson, Radiometric standards in space: The next step,. *Metrologia*, 37, 403-406, 2000; Pollock, D.B., T.L. Murdock, R.A. Datla, and A. Thompson, Data uncertainty traced to S.I. units: Results reported in the international system of units, *Int. J. Rem. Sensing*, 24, 225-235, 2003; World Meteorological Organization, *GCOS-7: Report of the GCOS Space-based Observation Task Group*, May 3-6, 1994, Darmstadt, Germany, WMO/TD No. 641, p.4, 1994; World Meteorological Organization, Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC, GCOS-92 (WMO/TD No. 1219), Geneva, Switzerland, 2004.

[42] National Research Council, *Solar Influences on Global Change*, National Academy Press, Washington, D.C., p. 1, 1994; Intergovernmental Panel on Climate Change, *Climate Change 1994, Radiative Forcing of Climate Change and an Evaluation of the IPCC 1992 IS92 Emission Scenarios*, J.T. Houghton, L.G. Meira Filho, J.P. Bruce, H. Lee, B.A. Callander, and E.F. Haites, eds., Cambridge University Press, Cambridge, 1995; Wilson, R.C., Total solar irradiance trend in solar cycles 21 and 22, *Science*, 277,1963-1965, 1997

[43] National Research Council, Radiative Forcing of Climate Change: Expanding the Concept and Addressing Uncertainties, National Academies Press, Washington, D.C., p. 112, 2005

The committee recommends that NASA, NOAA, and other agencies as appropriate accelerate efforts to create a sustained, robust, integrated observing system that includes at a minimum an essential baseline of climate observations, including atmospheric temperature and water vapor, spectrally resolved Earth radiances, and incident and reflected solar irradiance.

Climate Data Records and NPOESS

The NRC and others have recommended that NOAA embrace its new mandate to understand climate variability and change by asserting national leadership in applying new approaches to generate and manage satellite climate data records (CDRs), developing new community relationships, and ensuring long-term accuracy of satellite data records.[44] Climate data records are time series measurements of sufficient length and accuracy to determine climate variability and change. NOAA has stated its intention to use NPOESS to create CDRs.[45] However, the production, distribution, and stewardship of long-term climate records and the associated systematic testing and improvement of climate forecasts cannot be accomplished through the current NPOESS program or its data system architecture. As discussed above, baseline climate observations will be required, other satellite data records will have to be incorporated, and biases will have to be removed through testing for systematic errors on-orbit using independent techniques pinned to NIST absolute standards. These tasks will be sufficiently complex that a climate data and information system (a "Climate Central") will be needed, analogous to the operational weather prediction centers for environmental data records.[46] The Climate Central would benefit from having its own advisory council with international participation; moreover, the U.S.-funded Climate Central could become a node within an international virtual Climate Central. An associated data analysis and research program is also needed. The CCSP and Global Earth Observation initiatives provide a possible management structure through which NOAA could work to ensure that long-term climate records are created and maintained.

The committee recommends that NOAA, working with the Climate Change Science Program and the international Group on Earth Observations, create a climate data and information system to meet the challenge of ensuring the production, distribution, and stewardship of high-accuracy climate records from NPOESS and other relevant observational platforms.

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[44] National Research Council, *Climate Data Records from Environmental Satellites: Interim Report*, National Academies Press, Washington, D.C., 2004. See also Congressional testimony of Dr. Mark Abbott <http://www.house/gov/science/hearings/ets02/jul24/abbott.htm>.

[45] See <http://projects.osd.noaa.gov/NDE/pub-docs/NDE-1PgDescript.pdf> and NOAA's 2003 white paper plan to create CDRs at <http://cimss.ssec.wisc.edu/itwg/groups/climate/Creating_CDRs_from_NOAA_Satellites_White_Pager_18_Aug.pdf>.

[46] A.M. Goldberg, *Environmental Data Production and Delivery for NPOESS*, The MITRE Corporation, Work performed under NOAA contract 50-SPNA-9-00010, <http://www.mitre.org/work/tech_papers/tech_papers_02/goldberg_environmental/goldberg_environmental.pdf>.

4
Summary and Next Steps

In the coming decades, society's prosperity and security of will depend increasingly on Earth information, predictions, and warnings, which, in turn, rely fundamentally on sustained observations of the Earth system, linked to land and ocean observations and decision-support structures. Indeed, the need to improve this linkage was a key motivation for creating the Global Earth Observing System of Systems (GEOSS), which was initiated under U.S. leadership. During the next year the National Research Council's Committee on Earth Science and Applications from Space will carry out its decadal study to recommend new observing systems for Earth science research and operations. The structure of its panels roughly reflects the socio-economic benefit areas targeted by GEOSS (Table 4.1), an arrangement that will help ensure that the committee's recommended Earth research and observations can be applied for the specific benefit of society—now and for future generations.

TABLE 4.1 Relationship of NRC Panel Themes with GEOSS Socio-Economic Benefit Areas

Decadal Survey Panel Themes	GEOSS Socio-Economic Benefit Areas
Earth science applications and societal needs	• Supporting sustainable agriculture and combating desertification • Reducing loss of life and property from natural and human-induced disasters
Ecosystem health and biodiversity	• Improving the management and protection of terrestrial, coastal, and marine ecosystems • Understanding, monitoring, and conserving biodiversity
Weather	• Improving weather information, forecasting, and warning
Climate variability and change	• Understanding, assessing, predicting, mitigating, and adapting to climate variability and change
Water resources and the global hydrologic cycle	• Improving water resource management through better understanding of the water cycle
Human health and security	• Understanding environmental factors affecting human health and well-being
Solid-Earth hazards, resources, and dynamics	• Improving management of energy resources

A
Statement of Task

The Space Studies Board will organize a study, "Earth Observations from Space: A Community Assessment and Strategy for the Future." The study will generate consensus recommendations from the Earth and environmental science and applications community regarding science priorities, opportunities afforded by new measurement types and new vantage points, and a systems approach to space-based and ancillary observations that encompasses the research programs of NASA and the related operational programs of NOAA.

During this study, the committee will conduct the following tasks.

1. Review the status of the field to assess recent progress in resolving major scientific questions outlined in relevant prior NRC, NASA, and other relevant studies and in realizing desired predictive and applications capabilities via space-based Earth observations;
2. Develop a consensus of the top-level scientific questions that should provide the focus for Earth and environmental observations in the period 2005-2015;
3. Take into account the principal federal- and state-level users of these observations and identify opportunities and challenges to the exploitation of the data generated by Earth observations from space.
4. Recommend a prioritized list of measurements, and identify potential new space-based capabilities and supporting activities within NASA [Earth Science Enterprise] and NOAA [National Environmental Satellite, Data, and Information Service] to support national needs for research and monitoring of the dynamic Earth system during the decade 2005-2015. In addition to elucidating the fundamental physical processes that underlie the interconnected issues of climate and global change, these needs include: weather forecasting, seasonal climate prediction, aviation safety, natural resources management, agricultural assessment, homeland security, and infrastructure planning.
5. Identify important directions that should influence planning for the decade beyond 2015. For example, the committee will consider what ground-based and in-situ capabilities are anticipated over the next 10-20 years and how future space-based observing systems might leverage these capabilities. The committee will also give particular attention to strategies for NOAA to evolve current capabilities while meeting operational needs to collect, archive, and disseminate high quality data products related to weather, atmosphere, oceans, land, and the near-space environment.

The committee will address critical technology development requirements and opportunities; needs and opportunities for establishing and capitalizing on partnerships between NASA and NOAA and other public and private entities; and the human resource aspects of the field involving education, career opportunities, and public outreach. A minor but important part of the study will be the review of complementary initiatives of other nations in order to identify potential cooperative programs.

B
Acronyms and Abbreviations

ACRIM	Active Cavity Radiometer Irradiance Monitor
APS	Advanced Polarimetric Sensor
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CCSP	Climate Change Science Program
CDR	climate data record
CFC	chlorofluorocarbons
CMIS	Conical Scanning Microwave Imager/Sounder
EOS	Earth Observing System
ERB	Earth Radiation Budget
ERBS	Earth Radiation Budget Satellite
ESSP	Earth System Science Pathfinder
FY	fiscal year
GEOSS	Global Earth Observing System of Systems
GIFTS	Geostationary Imaging Fourier Transform Spectrometer
GOES	Geostationary Operational Environmental Satellite
GOES-R	Geostationary Operational Environmental Satellite-R (the next generation of GOES satellites)
GPM	Global Precipitation Measurement mission
GPS	Global Positioning System
GRACE	The Gravity Recovery and Climate Experiment
IBEX	Interstellar Boundary Experiment
InSAR	interferometric synthetic aperture radar
IPCC	Intergovernmental Panel on Climate Change
JPL	Jet Propulsion Laboratory
OLI	Operational Land Imager
LDCM	Landsat Data Continuity Mission
MTPE	Mission to Planet Earth
NASDA	National Space Development Agency (of Japan)
NASA	National Aeronautics and Space Administration
NIST	National Institute of Standards and Technology

NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPP	NPOESS Preparatory Program
NRC	National Research Council
NSCAT	NASA Scatterometer
OCO	Orbiting Carbon Observatory
OSTP	Office of Science and Technology Policy
SORCE	Solar Radiation and Climate Experiment
SPARCLE	SPAce Readiness Coherent Lidar Experiment
SLC	scan line corrector
TIM	Total Irradiance Monitor
TRMM	Tropical Rainfall Measuring Mission
WMO	World Meteorological Organization

C
Biographies of Committee Members and Staff

RICHARD A. ANTHES, *Co-chair,* is president of the University Corporation for Atmospheric Research, Boulder, Colorado. His research has focused on the understanding of tropical cyclones and mesoscale meteorology and on the radio occultation technique for sounding Earth's atmosphere. Dr. Anthes is a fellow of the AMS and the AGU, and is a recipient of the AMS Clarence I. Meisinger Award and the Jule G. Charney Award. In 2003 he was awarded the Friendship Award by the Chinese government, the most prestigious award given to foreigners, for his contributions over the years to atmospheric sciences and weather forecasting in China. His NRC service includes chairing the National Weather Service Modernization Committee from 1996-1999 and the Committee on NASA-NOAA Transition of Research to Operations in 2002-2003.

BERRIEN MOORE III, *Co-chair,* is Professor and Director of the Institute for the Study of Earth, Oceans, and Space, University of New Hampshire. A professor of systems research, he received the University's 1993 Excellence in Research Award and was named University Distinguished Professor in 1997. Moore's research focuses on the carbon cycle, global biogeochemical cycles, and global change as well as policy issues in the area of the global environment. He has served as several NASA advisory committees and in 1987 chaired the NASA Space and Earth Science Advisory Committee. Dr. Moore led the IGBP Task Force on Global Analysis, Interpretation, and Modeling (GAIM), prior to serving as Chair of the overarching Scientific Committee of the International Geosphere-Biosphere Programme (IGBP). As Chair of the SC-IGBP (1998-2002), Dr. Moore served as a lead author within the Intergovernmental Panel on Climate Change's (IPCC) Third Assessment Report which was released in Spring 2001. He chaired the July 2001 Open Science Conference on Global Change in Amsterdam and is one of the four architects of the Amsterdam Declaration on Global Change. Dr. Moore has contributed actively to committees at the NRC; most recently, he served as chairman of the NRC Committee on International Space Programs. From 1987 to 1992, he was a member of the NRC Board on Global Change and, of particular interest for this appointment, he chaired the NRC Committee on Global Change Research from 1995-1998. Dr. Moore current serves on the Science Advisory Board of NOAA and the Advisory Board of NCAR.

JAMES G. ANDERSON is the Philip S. Weld Professor in the Departments of Chemistry and Chemical Biology, Earth and Planetary Sciences, and the Division of Engineering and Applied Sciences at Harvard University. His interests include chemistry, dynamics and radiation of the Earth's atmosphere in the context of climate, experimental and theoretical studies of the kinetics and photochemistry of free radicals, and the development of new methods for in situ and remote observations of processes that control chemical and physical coupling within the Earth's atmosphere. He has served on the NRC Committee on Global Change Research (1996-2002), the Committee on Atmospheric Chemistry (1992-1995), and the Board on Atmospheric Sciences and Climate (1986-1989).

SUSAN K. AVERY is a professor of electrical and computer engineering and the former director of the Cooperative Institute for Research in Environmental Sciences. Currently, Dr. Avery is the vice-chancellor for research and dean of the University of Colorado, Boulder, Graduate School. Her research program utilizes ground-based Doppler radar techniques for observing the neutral atmosphere. Dr. Avery is currently the president of the American Meteorological Society. She has served as chair of the U.S. National Committee for the International Union of Radio Science; chair of the National Science Foundation Geosciences Advisory Committee; Scientific Discipline Representative and URSI Representative for SCOSTEP; and commissioner of the American Meteorological Society. She is a fellow of the AMS and the IEEE. Her NRC service includes the Committee on NOAA NESDIS Transition from

Research to Operations (vice chair, 2002-2004) and the Board on Atmospheric Sciences and Climate (1997-2001). She currently serves as a member of the Committee on Strategic Guidance for NSF's Support of the Atmospheric Sciences.

ERIC J. BARRON is dean of the College of Earth and Mineral Sciences and a distinguished professor of geosciences at the Pennsylvania State University. Before becoming dean, Barron was director of the EMS Environment Institute. Dr. Barron's research interests are in the areas of climatology, numerical modeling, and Earth history. He is a fellow of the American Geophysical Union, the American Association for the Advancement of Science, and the American Meteorological Society. He currently serves as chair of the NRC Committee on Metrics for Global Change Research. Dr. Barron's previous NRC service includes multiple terms on the NRC Board on Atmospheric Sciences and Climate (chair, 2000-2003; co-chair, 1997-1998; member, 1995-1996) and the Committee on Climate Research (member 1987-1990; chair, 1990-1996). Dr. Barron also served on the Committee on Science of Climate Change (2001), the Committee on Grand Challenges in the Environmental Sciences (1998-2000), the Task Group on Assessment of NASA Plans for Post-2000 Earth Observing Missions (1999), and the Committee on the Human Dimensions of Global Change (1991-1997), and the Board on Global Change Research (1990-1994). From 1994-1997 Dr. Barron chaired the NASA Earth Observing System, Science Executive Committee and in 1993 chaired the NASA Earth Science and Applications Advisory Committee.

OTIS B. BROWN is dean and professor of meteorology and physical oceanography of the Rosenstiel School of Marine and Atmospheric Science, University of Miami. Dr. Brown's specialties are satellite oceanography, development of quantitative methods for the processing and use of satellite remotely-sensed observations to study ocean variability, focused on ocean color and infrared observations. His experimental focus has been on western boundary current variability for the studies in the Somali Current, Gulf Stream, Agulhas and Brazil Confluence regions. More recently this effort has expanded to include development of basin scale climatologies for sea-surface temperature and color fields. Dr. Brown has published widely on the application of satellite observations to the understanding of oceanic processes and has served on numerous national and international scientific committees including: the U.S. Joint Global Ocean Flux Study, the Joint Committee on Global Ocean Observing Systems and the NOAA Advisory Panel on Climate and Global Change. His most recent awards include NASA's Public Service Group Achievement Award and election as a fellow of the American Association for the Advancement of Science. Dr. Brown's NRC service includes membership on the Ocean Studies Board (1998-2000), the Panel on Near-Term Development of Operational Ocean Observations (1991-1992), the Advisory Panel for the Tropical Ocean/Global Atmosphere (TOGA) Program (1985-1991), the Committee on Earth Studies (1996-1999).

SUSAN L. CUTTER is the director of the Hazards Research Laboratory and a Carolina Distinguished Professor of Geography at the University of South Carolina. Dr. Cutter has worked in the risk and hazards fields for more than twenty-five years and is a nationally recognized scholar in this field. She has provided expert advise to numerous governmental agencies in the hazards and environmental fields including NASA, FEMA and NSF. She has also authored or edited eleven books and more than seventy-five peer-reviewed articles and book chapters. In 1999, Dr. Cutter was elected as a fellow of the American Association for the Advancement of Science (AAAS), and she was president of the Association of American Geographers in 1999-2000. She currently serves on the NRC Geographical Sciences Committee, the Committee on Disaster Research in the Social Sciences, and the Panel on Social and Behavioral Science Research Priorities for Environmental Decision Making.

WILLIAM B. GAIL is director, advanced programs for Earth science, Ball Aerospace & Technologies Corporation. At Ball Aerospace, Dr. Gail is responsible for business development and proposal activities for NASA, NOAA, and international customers covering instruments, spacecraft, and space systems in the area of earth sciences and civil operational systems. Dr. Gail was instrumental in establishing international science mission partnerships in Europe and Asia and for developing innovative program implementation approaches, including government/commercial partnerships and commercial geo platform leasing for government payloads. He is currently a member of the NRC Committee on Earth Studies, and previously served on the Task Group on Principal Investigator-Led Earth Science Mission (2001-2003),the Committee on NASA-NOAA Transition from Research to Operations (2002-2003), and the Committee to Review the NASA Earth Science Enterprise Strategic Plan (2003).

BRADFORD H. HAGER is the Cecil and Ida Green Professor of Earth Sciences in the Earth, Atmospheric and Planetary Sciences Department at the Massachusetts Institute of Technology (MIT). Dr. Hager is best known for his research on the physics of geologic processes. He has focused his work on applying geophysical observations and numerical modeling to the study of mantle convection, the coupling of mantle convection to crustal deformation, and precision geodesy. From 1980 until he came to MIT, he was a professor of geophysics at the California Institute of Technology. Dr. Hager has chaired or been a member of several NRC committees concerned with solid-earth science. These include the U.S. Geodynamics Committee, the Geodesy Committee, the Committee for Review of the Science Implementation Plan of the NASA Office of Earth Science, and the Committee to Review NASA's Solid-Earth Science Strategy. Dr. Hager is a Fellow of the AGU. He was the 2002 recipient of the Geological Society of America's Woollard Award in recognition of distinctive contributions to geology through the application of the principles and techniques of geophysics;" he also received the AGU's James B. Macelwane Award for his contributions to understanding the physics of geologic processes.

ANTHONY HOLLINGSWORTH has been a staff member of the European Centre for Medium-range Weather Forecasting (ECMWF) since 1975. From 1991-2003, he served as the ECMWF's head of research and deputy director. Currently he is ECMWF's Coordinator for Global Earth-system Monitoring. He is the recipient of the 1999 American Meteorological Society's Jule G. Charney award for "penetrating research on four-dimensional data assimilation systems and numerical models". He is a fellow of the American Meteorological Society, of the Royal Meteorological Society, and is a member of the Irish Meteorological Society. Dr. Hollingsworth served on the NRC Panel on Model-Assimilated Data Sets for Atmospheric and Oceanic Research (1989-1991).

ANTHONY C. JANETOS is a senior research fellow at the H. John Heinz, III Center for Science, Economics, and the Environment. In 1999, he joined the World Resources Institute as senior vice president and chief of program. Previously, he served as senior scientist for the Land-Cover and Land-Use Change Program in NASA's Office of Earth Science, and was program scientist for the Landsat 7 mission. He had many years of experience in managing scientific research programs on a variety of ecological and environmental topics, including air pollution effects on forests, climate change impacts, land-use change, ecosystem modeling, and the global carbon cycle. He was a co-chair of the U.S. National Assessment of the Potential Consequences of Climate Variability and Change, and an author in the IPCC Special Report on Land-Use Change and Forestry, and the Global Biodiversity Assessment. Dr. Janetos recently served on the NRC Committee for Review of the U.S. Climate Change Science Program Strategic Plan and was a member of the Committee on Review of Scientific Research Programs at the Smithsonian Institution (2002).

KATHRYN KELLY is a principal oceanographer at the Applied Physics Laboratory of the University of Washington (UW) and a professor (affiliate) in the School of Oceanography. She is the former chair of the Air-sea Interaction/Remote Sensing (AIRS) Department at APL. Prior to her appointment at UW, Dr. Kelly worked at the Woods Hole Oceanographic Institution (WHOI) where she was part of the NASA Scatterometer (NSCAT) Science Working Team and began working with altimetric data. She is currently a member of the NASA Ocean Vector Wind Science Team and the NASA Ocean Surface Topography Science Team. At WHOI, she concentrated on the dynamics and thermodynamics of western and eastern boundary currents. Dr. Kelly's current scientific interest is primarily in the applications of large data sets, particularly from satellite sensors, to problems of climate, atmosphere-ocean interaction and ocean circulation. She works in collaboration with numerical modelers and scientists who make in situ measurements to better understand the ocean and to improve the quality of the satellite data. Dr. Kelly has served on numerous NASA advisory committees and was a member of the NRC Panel on Statistics and Oceanography (1992-1993).

NEAL F. LANE is the Edward A. and Hermena Hancock Kelly University Professor at Rice University. He also holds appointments as senior fellow of the James A. Baker III Institute for Public Policy, where he is engaged in matters of science and technology policy, and in the Department of Physics and Astronomy, and he previously served as university provost. Dr. Lane is a nationally recognized leader in science and technology policy development and application.. He has previously served as Assistant to the President for Science and Technology, Director of the White House Office of Science and Technology Policy, Director of the National Science Foundation, and Chancellor of the University of Colorado at Colorado Springs. Dr. Lane is a fellow of the American Physical Society, the American Academy of Arts and Sciences, the American Association for the Advancement of Science, and the Association for Women in Science. He currently serves as chair of the NRC Committee on Transportation of Radioactive Waste and he is also a member of the Policy and Global Affairs Committee.

DENNIS P. LETTENMAIER is a professor in the Department of Civil Engineering, and the director of the Surface Water Hydrology Research Group at the University of Washington. Dr. Lettenmaier's interests cover hydroclimatology, surface water hydrology, and GIS and remote sensing. He was a recipient of ASCE's Huber Research Prize in 1990, is a Fellow of the American Geophysical Union and American Meteorological Society, and is the author of over 100 journal articles. He is currently chief editor of the American Meteorological Society Journal of Hydrometeorology. Dr. Lettenmaier is a member of the NRC Committee on Hydrologic Science: Studies of Strategic Issues in Hydrology. He has served on other NRC committees and panels including the Committee on Hydrologic Science: Studies in Land-Surface Hydrologic Sciences (2002-2004), and the Committee on the National Ecological Observatory Network (2003-2004).

ARAM M. MIKA is vice president and general manager of the Advanced Technology Center in Palo Alto, California, where he leads research and development for Lockheed Martin Space Systems. The Advanced Technology Center is also Lockheed Martin's primary multidisciplinary R&D laboratory, with a technology portfolio that encompasses optics and electro-optics; precision control systems; guidance and navigation; materials and structures; RF, photonics and telecommunications; cryogenics and thermal sciences; space-science instrumentation; and modeling, simulation and information science. Moreover, the Advanced Technology Center produces payload instrumentation for space-science missions and provides technology consulting for other operating units throughout the Lockheed Martin Corporation. Prior to his career at Lockheed Martin, he was vice president of GM-Hughes Electronics (formerly Hughes Aircraft) and president of its Space Electro-Optics Business Unit, where he directed the design, development and production of spaceborne electro-optical sensors and associated signal/data processing systems for civil space and DOD applications. These products included sensors and systems for earth remote sensing, meteorology, planetary-exploration missions, and defense applications such as missile warning and tracking. Previously at Hughes, Mr. Mika served as vice president of the Santa Barbara Research Center and general manager of its systems division where he led the development of space-instrument payloads for NASA, NOAA and international customers. Mr. Mika has also been extensively engaged in numerous advisory panels, review boards, committees and conferences on space remote-sensing, including the NRC Task Group on Technology Development in NASA's Office of Space Science (1998) and the Committee on Earth Studies (1995-1998).

WARREN M. WASHINGTON is a senior scientist and head of the Climate Change Research Section in the Climate and Global Dynamics Division at the National Center for Atmospheric Research (NCAR).

After completing his doctorate in meteorology at Pennsylvania State University, he joined NCAR in 1963 as a research scientist. Dr. Washington's areas of expertise are atmospheric science and climate research, and he specializes in computer modeling of the earth's climate. He serves as a consultant and advisor to a number of government officials and committees on climate-system modeling. From 1978 to 1984, he served on the President's National Advisory Committee on Oceans and Atmosphere. In 1998, he was appointed to the National Oceanic and Atmospheric Agency Science Advisory Board. In 2002, he was appointed to the Science Advisory Panel of the U.S. Commission on Ocean Policy and the National Academies of Science Coordinating Committee on Global Change. Dr. Washington's NRC service is extensive and includes membership on the Board on Sustainable Development (1995-1999), the Commission on Geosciences, Environment, and Resources (1992-1994), the Board on Atmospheric Sciences and Climate (1985-1988), and his service as chair of the Panel on Earth and Atmospheric Sciences (1986-1987). He is a member of the National Science Board and currently serves as the chair.

MARK L. WILSON is Professor of Epidemiology, Director of Global Health Program, and Professor of Ecology and Evolutionary Biology at the University of Michigan. His research and teaching cover the broad area of ecology and epidemiology of infectious diseases. After earning his doctoral degree from Harvard University in 1985, he worked at the Pasteur Institute in Dakar Senegal (1986-90), was on the faculty at the Yale University School of Medicine (1991-96), and then joined the University of Michigan. Dr. Wilson's research addresses the environmental determinants of zoonotic and arthropod-borne diseases, the evolution of vector-host-parasite systems, and the analysis of transmission dynamics. He is an author of more than 120 journal articles, book chapters and research reports, and has served on numerous governmental advisory groups concerned with environmental change and health. Dr. Wilson has served on the NRC Committee on Emerging Microbial Threats to Health in the 21st Century (2001-2003), the Committee on Review of NASA's Earth Science Applications Program Strategic Plan (2002), and the Committee on Climate, Ecosystems, Infectious Diseases, and Human Health (1999-2001).

MARY LOU ZOBACK is a senior research scientist with the U.S. Geological Survey's Earthquake Hazards Team, Menlo Park, Calif. She is a respected geophysicist recognized for her work on the relationship between earthquakes and state of stress in the Earth's crust. From 1986 to 1992, Dr. Zoback created and led the World Stress Map project, an effort that actively involved 40 scientists from 30 different countries, with the objective of interpreting a wide variety of geologic and geophysical data on the present-day tectonic stress field. Dr. Zoback was awarded the American Geophysical Union's Macelwane Award in 1987 for "significant contributions to the geophysical sciences by a young scientist of outstanding ability," and a USGS Gilbert Fellowship Award (1990-1991). She is a former president of both the Geological Society of America and AGU's Tectonophysics Section, and was a member of the AGU Council. Dr. Zoback has extensive Academy wide service and currently serves on theNAS Council and the National Academies Committee on Science, Engineering, and Public Policy. She served as a member of the Board on Radioactive Waste Management (1997-2000), and the Commission on Geosciences, Environment, and Resources (1998-2000).

Staff

ARTHUR CHARO, study director, received his Ph.D. in physics from Duke University in 1981 and was a postdoctoral fellow in chemical physics at Harvard University from 1982 to 1985. Dr. Charo then pursued his interests in national security and arms control at Harvard University's Center for Science and International Affairs, where he was a fellow from 1985 to 1988. From 1988 to 1995, he worked in the International Security and Space Program in the U.S. Congress's Office of Technology Assessment (OTA). He has been a senior program officer at the Space Studies Board (SSB) of the National Research Council since OTA's closure in 1995. Dr. Charo is a recipient of a MacArthur Foundation Fellowship in International Security (1985-1987) and was the American Institute of Physics Congressional Science Fellow from 1988 to 1989. He is the author of research papers in the field of molecular spectroscopy;

reports on arms control and space policy; and the monograph, *Continental Air Defense: A Neglected Dimension of Strategic Defense* (University Press of America, 1990).

ANNE M. LINN, senior program officer, received her Ph.D. in geology from the University of California, Los Angeles, in 1991. Following a postdoctoral research position in geochemistry at the University of California, Berkeley, and a visiting research position at the Carnegie Institution of Washington for one year, she joined the National Academies' Board on Earth Sciences and Resources in 1993. There she has worked on a wide variety of studies in geophysics, Earth observing systems, and data, culminating in 19 National Research Council reports. Dr. Linn also volunteers for two committees under the International Council for Science (ICSU). She is the secretary of the ICSU Panel on World Data Centers and a member of the ICSU ad hoc Committee on Data and Information.

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