NASA'S EARTH SCIENCE AND APPLICATIONS PROGRAMS: FISCAL YEAR 2008 BUDGET REQUEST AND ISSUES

HEARING

BEFORE THE

SUBCOMMITTEE ON SPACE AND AERONAUTICS

COMMITTEE ON SCIENCE AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

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NASA'S EARTH SCIENCE AND APPLICATIONS PROGRAMS: FISCAL YEAR 2008 BUDGET REQUEST AND ISSUES

THURSDAY, JUNE 28, 2007

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON SPACE AND AERONAUTICS,
COMMITTEE ON SCIENCE AND TECHNOLOGY,
Washington, DC.

The Subcommittee met, pursuant to call, at 10:05 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Mark Udall [Chairman of the Subcommittee] presiding.

U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE AND TECHNOLOGY
SUBCOMMITTEE ON SPACE AND AERONAUTICS

Hearing on

NASA's Earth Science and Applications Programs: Fiscal Year 2008 Budget Request and Issues

June 28, 2007
10:00 a.m. – 12:00 p.m.
2318 Rayburn House Office Building

WITNESS LIST

Dr. Michael H. Freilich
Director
Earth Science Division
NASA

Dr. Richard A. Anthes
President
Universities Corporation for Atmospheric Research

Dr. Eric J. Barron
Dean
Jackson School of Geosciences
The University of Texas, Austin

Dr. Timothy W. Foresman
President
International Center for Remote Sensing Education

HEARING CHARTER

SUBCOMMITTEE ON SPACE AND AERONAUTICS COMMITTEE ON SCIENCE AND TECHNOLOGY U.S. HOUSE OF REPRESENTATIVES

NASA's Earth Science and Applications Programs: Fiscal Year 2008 Budget Request and Issues

THURSDAY, JUNE 28, 2007
10:00 A.M.–12:00 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING

Purpose

On Thursday, June 28, 2007 at 10:00 am, the House Committee on Science and Technology's Subcommittee on Space and Aeronautics will hold a hearing to examine the National Aeronautics and Space Administration's (NASA) Fiscal Year 2008 budget request and plans for the Earth science and applications programs, and issues related to the programs.

Witnesses:

Witnesses scheduled to testify at the hearing include the following:

Dr. Michael H. Freilich, Director, Earth Science Division, Science Mission Directorate, NASA

Dr. Richard A. Anthes, President, Universities Corporation for Atmospheric Research

Dr. Eric J. Barron, Dean, Jackson School of Geosciences, University of Texas, Austin

Dr. Timothy W. Foresman, President, International Center for Remote Sensing Education

Potential Issues

The following are some of the potential issues that might be raised at the hearing:

What is the future direction of NASA's Earth Science program?

- The authors of the recently released National Academies' report, *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond* (the "decadal survey") found that "The NASA/NOAA Earth Observation Satellite system, launched at the turn of the millennium, is aging and the existing plan for the future is entirely inadequate to meet the coming challenges." (Attachment 1) Over the last two years, for example, several missions or instruments that were planned to study the climate, weather, precipitation, and land cover changes have been descoped, delayed, on the brink of cancellation, or canceled. Examples of these decisions are listed below and in Attachment 2.
    - Deep Space Climate Observatory (decision not to launch)
    - Hydros mission to measure soil moisture (canceled)
    - Global Precipitation Mission (delayed)
    - National Polar-orbiting Operational Environmental Satellite System (NPOESS) (descoped and delayed)
    - Glory (delayed)
    - Landsat Data Continuity Mission (changing acquisition approaches, possible data gaps)

  The authoring committee recommended a set of observing systems and supporting research and technology elements needed to meet the high priority Earth science and socioeconomic challenges that face our planet over the next decade. The committee estimated that returning to the FY 2000 budget level for NASA's Earth science and applications program—approximately $2 billion per year—would be sufficient for building the recommended program. (Attachment 3) The President's FY 2008 budget request for NASA's Earth science and applications program and the projections through FY 2012, however, do not include resources for initiating the future missions or research activities recommended in the decadal survey. What is NASA's plan for implementing the Earth sciences decadal survey and what is the timeline? What future direction will NASA's Earth science and applications program take given the available resources? Which of the decadal survey priorities will be addressed and what observations will be made?

How Important Are Observations from NASA's Earth Science Missions to the Nation's and the World's Overall Climate Research Efforts?

- The recent release of the Fourth Assessment Report of the International Panel on Climate Change (IPCC) Working Group I found that the climate is warming and the catalysts for that warming are due, in part, to human contributions of greenhouse gases to the Earth's atmosphere. To what extent did data from NASA Earth observing satellites contribute to the IPCC assessment and which missions recommended in the Earth science decadal survey can help reduce uncertainties mentioned in the report? At the national level, an "Overview of U.S. Research in Climate and Global Change," noted that "The USGCRP [U.S. Global Change Research Program] and *Climate Change Research Initiative* (CCRI) will place major emphasis on requirements-driven specification of comprehensive observing systems. . ..." The attributes of those systems would include:
    - "Development of new observing capabilities to illuminate Earth system processes and increase spatial, temporal, or spectral resolution where needed to reduce key uncertainties in climate change and address emerging Earth science questions. . ..
    - Special emphasis on the complex observations and monitoring systems needed to analyze terrestrial and aquatic ecosystem variability."

  Are NASA's plans for Earth Science and Applications consistent with the goals set out in the U.S. Global Change Research Program and Climate Change Research Initiative? How important are NASA's Earth observation satellites to the Nation's and the world's climate research efforts? What percentage of the world's space-based climate monitoring is performed by NASA's Earth observing sensors? What percentage of the Nation's and the world expenditures on climate research does NASA's contribution represent? What is the potential impact on plans and policies for adapting to climate change if new observing systems are not developed?

- **Leadership in Future Earth Sciences and Applications Activities**

  According to the decadal survey, "Sustained multi-decadal, global measurements and data management of quantities that are key to understanding the state of the climate and the changes taking place are crucial." Sustaining multi-decadal measurements requires commitment and leadership, as noted by the survey's call for the U.S. Government to restore leadership in Earth sciences and applications. In a recent interview on National Public Radio's (NPR) Morning Edition program, the NASA Administrator said, "I have no doubt that. . .a trend of global warming exists. I am not sure that it is fair to say that it is a problem we must wrestle with." NASA's own scientists use NASA Earth observation data to research Earth's climate. Dr. Griffin has since apologized for his remarks on NPR to employees at the Jet Propulsion Laboratory, yet his statements are leading some people to question NASA's commitment to leadership in climate monitoring and Earth science. How committed are the agency and the nation to ensuring U.S. leadership in Earth sciences and applications? To what degree will leaders commit to multi-decadal, global measurements of the Earth system?

How Well Balanced is the NASA Earth Sciences Program?

- The National Academies' decadal survey emphasized that NASA's Earth science and applications program must be balanced across scientific disciplines within Earth system science; across mission sizes (small, medium, and large); technology maturity; and between observations and analysis, modeling, and applications. Does NASA agree with this definition of balance? How well is NASA's current Earth science and applications program balanced according to these elements? What performance measures might be used to assess balance within and among NASA's Earth science program elements?

  - *Importance of the Grants Program (Research and Analysis)* The decadal survey raises concern about reductions in the research and analysis accounts (grants for interpreting data, developing new concepts for algorithms, models, technology, and missions, and for training graduate students) and emphasizes the need for a strong R&A program to support the ongoing and planned missions. According to a 2006 National Academies report, *An Assessment of Balance in NASA's Science Programs,* "The most serious impacts on the long-term strategy and capacity-building efforts in Earth science will result from the severe cuts in the R&A program. Although the proposed R&A cuts across NASA are approximately 15 percent, the cuts for FY 2007 appear to be closer to 20 percent in key elements of the Earth sciences." In a constrained resource environment, are there elements of a balanced program, such as R&A, that should be protected beyond others? If so, what are they? What is the appropriate mechanism for assessing balance and making adjustments as needed? What threshold of R&A resources is required to ensure a healthy program? Are there measures to assess the effectiveness of investments in R&A?

What is NASA Doing to Better Utilize Earth Science Research Data to Address Societal Needs?

- The National Academies Earth science decadal survey stresses the importance of "advances in fundamental understanding of the Earth system and increased application of this understanding to serve the nation and the people of the world." NASA's Earth science applications program supports competitively selected proposals to apply NASA Earth science research results, technologies, and data to high priority societal needs. Those priorities include agricultural efficiency, coastal management, energy management, air quality, and public health among other application areas. The applications program focuses on developing federal decision support tools. Is NASA's application program structured to address the decadal survey's recommendations on applications for societal benefit? What, if any, changes to NASA's applications program are needed to make NASA's Earth science information more responsive to societal needs?
  - *NASA Authorization Act and Earth Science Applications.* Section 313 of the *NASA Authorization Act of 2005* directs NASA to "establish a program of grants for competitively awarded pilot projects to explore the integrated use of sources of remote sensing and other geospatial information to address State, local, regional, and tribal agency needs." NASA's response to Section 313, so far, has been to note in its grant solicitations that the applications program supports organizations with connections to State, local, regional, and tribal constituencies. Does this step represent any change to grant solicitations prior to the Authorization Act? Is NASA's response sufficient to address the Section 313 directive? How many grants does NASA issue that directly address State, local, regional and tribal needs? To what extent do national decision support systems serve as pilot projects to address State, local, regional, and tribal agency needs?"
  - *Commercial Initiatives in Using Earth Observation Data.* Google Earth and Microsoft Virtual Earth are making Earth observation data available over the Internet at no cost to users. What impacts are these initiatives having on the use of NASA—provided Earth observations data for applications? What is NASA's relationship to these commercial enterprises?

What is the Fate of the Climate Instruments That Were Removed From NPOESS?

- When the NPOESS program was certified under Nunn-McCurdy, a number of climate sensors were removed from the system and the coverage and/or capability of some sensors was reduced. Following the Nunn-McCurdy certification, OSTP requested that NASA and NOAA assess the impacts of the demanifested climate sensors on NASA's and NOAA's climate objectives. OSTP also asked the agencies to propose options for mitigating the impacts. At a recent meeting at the National Academies Panel on Options to Ensure the Climate Record from the NPOESS and GOES–R Spacecraft, NASA and

NOAA described several possible mitigation strategies including returning some of the lost climate sensors to NPOESS satellites; placing climate sensors on other (non-NPOESS) planned Earth science platforms; developing free-flyer platforms to fly the sensors; or partnering with other U.S. agencies to fly sensors or obtain the data. NASA and NOAA have asked the National Academies to provide further input on options to mitigate the impact of the lost sensors. NASA and NOAA are developing a set of near-term actions and cost estimates to inform OMB and OSTP for the FY 2009 budget process. What are the implications of potential data gaps on U.S. climate research and monitoring? What contribution can the missions recommended in the Earth science decadal survey make to minimizing potential data gaps? To what extent will the reduced capability/coverage of the sensors being retained in the NPOESS program compromise the measurements needed for climate research and monitoring? How well do the possible mitigation strategies address the required accuracy for climate research measurements? When will funding decisions be needed to accommodate development of satellites and sensors on a schedule that avoids potential data gaps?

What Is NASA's Plan for Transitioning Research Data and Instruments into Operational Services?

- NASA research satellites often provide vital data for ongoing, operational services such as weather prediction and disaster warnings. For example, data from the NASA QuikSCAT satellite, which measures ocean wind speed and direction, is being used at NOAA's National Hurricane Center to help determine a hurricane's path. In a May 8, 2007 letter to NASA Administrator Michael Griffin and NOAA Under Secretary Vice Admiral Conrad Lautenbacher, Jr., Representative Nick Lampson voiced concerns about the lack of planning for a successor to QuikSCAT, which has started its ninth year of operation and is six years beyond its designed lifetime. Without QuikSCAT data, hurricane predictions and evacuation plans would be less accurate. The QuikSCAT example points to the larger challenge, as noted by Rep. Lampson, for NASA and NOAA to "systematically evaluate the technology and capabilities from NASA's Earth-observing missions for application to NOAA's operational responsibilities." What are NASA's and NOAA's plans for a follow-on to QuikSCAT and what is the status of those plans?
    - *Congressional Legislation* Section 306 of the *NASA Authorization Act of 2005* directed NASA and NOAA to establish a joint working group and report on coordination between the agencies on Earth science missions and their potential for transition into operational service. In addition, the Earth science decadal survey states that "The committee is particularly concerned with the lack of clear agency responsibility for sustained research programs and the transitioning of proof-of-concept measurements into sustained measurement systems." To date, NASA and NOAA have not established a plan for transitioning research into operations, and Congress continues to await NASA and NOAA's response to the Authorization Act's directive. What is NASA's and NOAA's plan for transitioning from research to operations? As NASA considers moving forward with missions recommended in the decadal survey, how and when will decisions on research to operations be made?

What role should international partners play in NASA's future Earth science system?

- NASA has a long history of using international and bilateral cooperation on Earth science missions. NASA's Upper Atmosphere Research Satellite launched in 1991 included instruments from the United Kingdom and from a French-Canadian team. U.S.-French collaboration on the Topex/Poseidon and follow-on Jason satellites to measure sea surface height and the U.S.-Japanese collaboration on the Tropical Rainfall Measuring Mission (TRMM) and the Global Precipitation Mission (GPM) that is currently in development are examples of bilateral cooperation. The decadal survey discusses international cooperation as a means for realizing the missions recommended in the report. In a hearing of the House Subcommittee on Space and Aeronautics held on May 2, Dr. Alan Stern, Associate Administrator for NASA's Science Mission Directorate, testified that he plans to "make strong progress advancing all four decadal surveys. . .by increasing our international collaboration efforts." Dr. Stern also testified that NASA is considering international arrangements in which the agency "would collaborate at higher, more strategic level." What, in specific terms, do Dr. Stern's proposals mean for future NASA Earth science missions? What steps has NASA taken to explore potential international arrangements on future Earth science missions? What are the opportunities and risks for working with international partners to advance the missions recommended in the decadal survey? Are there mission areas, technology areas, or measurements and observations that the U.S. should carry out on a unilateral basis to maintain leadership?

What are NASA's Near and Long-term Plans for Sustaining Land Cover Observations?

- NASA's Landsat system has collected land cover data for over thirty years. These data are used by U.S. Government, scientific, State and local governments, non-profit organizations, and international entities to study land use and change. The currently operating Landsat 7 satellite has lost 25 percent of its imaging capability, according to NASA officials. Landsat 7 is expected to cease useful operation by 2010 at which point NASA anticipates a 6–12 month gap in the collection of Landsat data until the follow-on satellite, the Landsat Data Continuity Mission (LDCM), enters service in 2011. NASA is involved in a Data Gap Study Team to assess "alternatives to at least partially offset the data gap." NASA is investigating whether data from international satellites, including an Indian satellite and a Chinese/Brazilian land observing system could help address the data gap.
    - *Instability in the Landsat Program* Since 1999, NASA has shifted its procurement approach for LCDM three times. Approaches have included a public-private partnership, placement on the NPOESS platform, and finally the current plan for a free-flying mission to be developed and launched by NASA and operated by USGS. These procurement struggles echo a longer history of difficulties in maintaining the program. What is the current status of LDCM? Will LDCM provide data that is comparable to or better than Landsat 7? How likely is a data gap prior to the LDCM availability? What lessons from the Landsat experience can be applied to plans for future long-term observation systems, such as those being considered for climate monitoring?
    - *LDCM and Thermal Imaging Capability* LDCM includes one instrument, the Operational Land Imager (OLI). According to NASA officials, this instrument will not image in thermal bands, a capability that has been provided on the last three Landsat spacecraft. The data collected in the thermal bands provide information to assist in the management of water resources, in particular agricultural water uses. Adding thermal imaging capability to LDCM will increase the mission cost and delay the schedule. Is NASA considering alternatives to LDCM for providing thermal image data?
    - *LDCM as a Possible Platform for a Climate Sensor* NASA officials have also indicated that LDCM is being considered as a potential platform on which to fly a Total Solar Irradiance Sensor (TSIS)—one of the climate sensors demanifested from the NPOESS system. When will a decision on adding a sensor to LDCM be made? How would adding the TSIS sensor affect the cost and schedule of the LDCM mission, including the length of the gap in land cover data?
    - *Policy for Maintaining the Long-Term Land Cover Record* The Office of Science and Technology Policy (OSTP) is preparing a long-term plan for acquiring moderate resolution, space-based land observation data following the launch of LDCM in 2011. The *Landsat Policy Act of 1992* seeks to ensure the continuity of Landsat data. What is the status of OSTP's development of a long-term plan for moderate resolution land imagery? What would an operational program mean, in specific terms, for the U.S.? What role would NASA have in an operational land observing program? What responses do the science and user communities have to the goal of an operational Landsat system?

Is a National Strategy for Earth Monitoring Across Relevant Agencies Needed?

- NASA has the largest program in the U.S. Government for observing the Earth and supporting research to understand the Earth system. Other agencies such as NOAA and the Department of the Interior's U.S. Geological Survey (USGS) also monitor the Earth system and fund Earth science research. How does NASA coordinate with NOAA, USGS, and other federal agencies on

Earth observations? Has coordination among NASA, NOAA, and USGS been successful, and if not, why not? Should the U.S. consider a "National Earth-Information Initiative," as proposed by former Presidential Science Advisor, Neal Lane, and others "to reevaluate the national process of collecting and using civil Earth information, including the effectiveness of governmental organizations, the relationship between government functions and private sector activities, and the ability to effectively connect scientific developments to societal uses"? The authors recommend that a blue ribbon panel be created to consider improvements to the Nation's process of collecting and using Earth information. What are the pros and cons of such as proposal? What approach have other nations and regions, such as Europe, Japan, and China taken to exploit Earth information? How important is a potential Earth information strategy to U.S. national competitiveness?

BACKGROUND

Fiscal Year 2008 Budget Request

The President's Fiscal Year 2008 budget request includes $1.497 billion for NASA's Earth science and applications programs, an increase of two percent over the Fiscal Year 2007 budget request. In the FY 2008 request, increases over the President's FY 2007 budget estimate for FY 2008 were required on several missions as a result of schedule delays and cost overruns. Those missions include the Global Precipitation Measurement (GPM), Glory, Landsat Data Continuity Mission (LDCM), NPOESS Preparatory Mission (NPP), and Aquarius mission. In addition, NASA canceled the Hydros mission, which was designed to measure soil moisture, due to the agency's lack of funding to support it. Attachment 4 provides details on the FY 2008 budget request for NASA's Earth sciences and applications programs.

NASA Earth Science Program Elements

- The Earth Science Research Program provides grant support for research and analysis activities (e.g., basic research, modeling, and technology development); research on interdisciplinary science from the Earth observing system; suborbital projects (aircraft and uncrewed aircraft); the use of supercomputers for the development of Earth science models; and access to supercomputers for users from other agencies.
- The Earth sciences applications program supports competitively selected grants to apply results from NASA Earth science research to societal benefit areas. Specific areas of applications include agricultural efficiency, air quality, aviation, carbon management, coastal management, disaster management, ecological forecasting, energy management, homeland security, invasive species, public health, and water management. The applications program involves two components:
    - **National Applications** matches decision support systems in Federal agencies with information from NASA Earth science research that can benefit from the additional NASA information.
    - **Crosscutting Solutions** supports the National Applications decision support projects by providing systems integration, engineering, and the development of prototypes.
- Earth Science Multi-Mission Operations is dedicated to archiving, preserving, and disseminating Earth science data. The primary data management system for Earth science data is the Earth Observing System Data and Information System (EOSDIS). EOSDIS handles four terabytes of incoming data from the Earth observing system (the Aqua, Terra, and Aura satellites) per day and consists of eight Distributed Active Archive Centers (DAACs). The DAACs are located at universities and research facilities across the country and distribute the data to users.
- Earth Systematic Missions include over a dozen Earth science satellites that are collecting data about the Earth and its atmosphere and other missions that are in development. Many of the Earth Systematic Missions enable researchers to study Earth's changes in and effort to improve predictions of climate, weather, and natural hazards. Key missions include:
    - The Global Precipitation Measurement (GPM). GPM is a joint U.S.-Japanese mission to measure precipitation at a frequent rate across the globe and enable correlation of precipitation measurements. GPM, which consists of two spacecraft, is expected to help improve the prediction of flood

hazards and measurements of fresh water resources. GPM spacecraft are planned for launch in 2013 and 2014.

  - The Glory mission will study the properties and chemical composition of aerosols and clouds. Data collected from the Glory spacecraft will provide insights into the natural and anthropogenic contributions to climate change. Glory is planned for launch in 2008.
  - The Landsat Data Continuity Mission (LDCM) is the follow-on mission to the Landsat 7 satellite. The objective of LDCM is to continue the thirty-year data record of moderate resolution, multi-spectral land observations, which are used by U.S. Government, scientific, State and local governments, and other communities to study land use and change. LDCM is slated for launch in 2011.
  - The NPOESS Preparatory Project (NPP) will continue measurements of atmospheric and sea surface temperatures; humidity sounding; land and ocean biological productivity; cloud and aerosol properties that are being collected on NASA Earth observing missions (Terra, Aqua, Aura). NPP is also intended to reduce the risk of sensors being planned for the operational NPOESS system. NPP, which is a joint program with NOAA and the DOD, is slated to launch in 2009. Technical issues related to NPP are:
    - The Visible/Infrared Radiometer Suite (VIIRS) instrument has encountered technical problems that will affect ocean color and aerosol studies. According to a recent *Space News* article on VIIRS, the contractor and NPOESS program officials are evaluating possible solutions to the problem. A science team is analyzing what level of capability is needed from VIIRs to obtain science-quality measurements and whether such a capability can be met.
    - A flight model of the Cross-track Infrared Sounder (CrIS) experienced a failure during a vibration test. The instrument will undergo additional tests.
    - The Ozone Mapping and Profiling Suite (OMPS) Limb sensor was removed from the NPOESS program during Nunn-McCurdy. NASA and NOAA have decided to add the OMPS Limb sensor to NPP and to split the costs.
  - The Quick Scatterometer (QuikSCAT) is a satellite launched in 1999 to measure wind speed and direction, factors that hurricane forecasters have come to rely on to “measure the size of a developing storm’s wind field, and in some cases to locate its center of circulation,” according to a *Space News* article on “Scientists Exploring Options for QuikScat Successor.” QuikSCAT measurements contribute to climate change research, for instance, through the study of the movements and changes of sea ice and Arctic and Antarctic ice packs. The data are also used to investigate changes in rain forest vegetation. Issues with QuikSCAT are:
    - The lack of a back-up satellite or planned back-up, should QuikSCAT fail.
    - The implications of losing QuikSCAT on the accuracy of hurricane monitoring.
- The Earth System Science Pathfinder (ESSP) Program solicits proposals for scientists to propose small to medium-sized missions that can involve studies of the atmosphere, oceans, land surface, polar ice regions, and solid Earth. Upon selection, scientists are granted the funds to serve as principal investigator of the mission and are responsible for the scientific and technical success of the mission. ESSP missions complement larger missions, but are conducted on shorter timescales.
  - The next solicitation for ESSP proposals is expected in late FY 2008. This represents a gap of approximately seven years since the last ESSP solicitation in 2001.
- The Education and Outreach program provides support for fellowships and new investigators, as well as K–16 education. The FY 2008 program will focus on the activities of the International Polar Year.
- The Earth Science Technology program includes development of new instruments and measurement techniques, information technologies, and technologies for the Earth science program. NASA’s Langley Research Center and

Goddard Space Flight Center are focusing on laser development technologies that can be applied to future Earth science missions.

Global Earth Observation System of Systems

NASA is a member of the group overseeing the U.S. contribution to a Global Earth Observation System of Systems (GEOSS). GEOSS is an international effort to share the Earth observation data collected from space, ground, and air observatories by individual nations. By creating a common format for the data and providing a means for integrating and sharing the data, GEOSS will allow for a richer set of data by which to address national and international societal needs and to support scientific research of the Earth system. The U.S. and international members that are working toward GEOSS are focusing on key societal issues that can benefit from the shared and integrated data enabled by GEOSS. Focus areas include improved observations for disaster reduction, a National Integrated Drought Information System; and Air Quality Assessment and Forecast. NASA's Earth science applications program is involved in providing the U.S. contribution to the GEOSS societal benefit areas.

Summary of February 13, 2007 Hearing of the Committee on Science and Technology on National Imperatives for Earth and Climate Science Research and Applications Investments Over the Next Decade

The Committee on Science and Technology of the House of Representatives held a hearing on February 13, 2007 to review the results of the National Academies report, *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond.*

- Dr. Richard Anthes, President, University Corporation for Atmospheric Research and Co-Chair, Committee on Earth Science and Applications From Space, National Research Council, National Academies testified that "at a time when the need has never been greater, we are faced with an Earth observation program that will dramatically diminish in capability over the next five to ten years." The resulting impacts are likely to include less accurate weather forecasts, uncertainty about the rate of rising sea levels and uncertainty about the intensity of hurricanes, for example. It is critical to measure the imbalance between the radiation the Sun is putting out and what is going out from the Earth and back into space, a factor that is contributing to global warming. Dr. Anthes noted that implementing the missions recommended in the Earth science decadal survey is not just important for reducing the risks of natural hazards, it is important for managing our natural resources, including water, energy, fisheries, and ecosystems more efficiently.
- Dr. Berrien Moore, III, University Distinguished Professor, Director, Institute for the Study of Earth, Oceans, and Space, University of New Hampshire; Co-Chair, Committee on Earth Science and Applications from Space, National Research Council, The National Academies testified that NASA's Earth science budget has decreased by 33 percent in real terms since 2000. Any budget increases that NOAA enjoyed during the same period were diverted to NPOESS, which suffered from technical and managerial problems. The decadal survey "set forth a strategy for a strong, balanced national program in Earth science to reverse this trend." He noted that by using small missions rather than large missions with multiple instruments, the decadal strategy could be implemented for a reasonable investment, in particular, the budget levels provided for Earth science in the year 2000. Dr. Moore testified that the Fiscal Year 2008 budget is not sufficient to enable the implementation of the decadal survey. While it does provide resources to move forward with high priority missions already underway, the FY 2008 budget, "will leave NASA's Earth science with nearly 50 percent less buying power in comparison to the year 2000 and. . .by 2012 will put us at a 20-year low in real terms for Earth science."
- NOAA's budget is insufficient to address the growth in cost of the NPOESS and GOES–R missions or to restore the losses of climate measurements that were removed from the NPOESS program. He noted that a small investment, $70M, in early technology development for the recommended missions would be a good first step in implementation. Dr. Moore testified that finding the additional funds to move forward should focus on the benefits of Earth observations including increased reliability in infectious disease forecasts, monitoring of crustal movements and identifying active faults, and improved precipitation and drought forecasts, among other benefits.

- Honorable James Geringer, Director of Policy and Public Sector Strategy, Environmental Systems Research Institute (ESRI) testified that drought can be longer-term and more widespread than tornadoes, floods, hurricanes, and earthquakes. He noted that 19 western governors convened to support the use of satellite data to reduce the impact of droughts on the region, and requested funds for the National Integrated Drought Information System. He noted that the decadal survey explored issues including the benefits of Earth science data. Mr. Geringer also discussed the frustration that users experience by the lack of access to and the relevance of remote sensing data to their needs. Mr. Geringer recommended, based on the decadal survey, that the people should have the best possible information to respond to their changing environments, and to protect their lives, livelihood, and property. He also recommended that an Integrated Earth Observation System be provided to ensure U.S. competitiveness. He referred to the activities of the private sector, including Google Earth, Microsoft Virtual Earth, and other tools that use remote sensing imagery and the data provided by commercial space remote sensing companies. He noted that users "want objective, timely, and accurate information." He discussed the need for a system that integrates space, ground, airborne, and ocean-based sensors as well as a web-based network that integrates the information.

ATTACHMENT 1

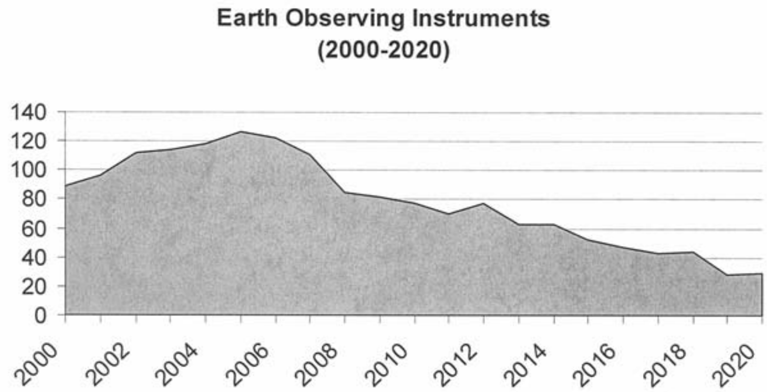

Figure 1. Number of current and planned U.S. space-based Earth Observations instruments, not counting the recommended missions in the Committee's report. For the period from 2007 to 2010, missions were generally assumed to operate for four years past their nominal lifetimes. SOURCE: Information from NASA and NOAA websites for mission durations.

Source: Testimony of Dr. Richard Anthes, at a Hearing of the Committee on Science and Technology, held on February 13, 2007 on National Imperatives for Earth and Climate Science Research and Applications Over the Next Decade.

ATTACHMENT 2

Canceled, Descoped, or Delayed Earth Observation Missions
(from the April 2005 Pre-Publication of the Interim Report of the Decadal Survey on Earth Science and Applications from Space)

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

Source: Testimony of Dr. Berrien Moore, III, at a Hearing of the Committee on Science and Technology, held on February 13, 2007 on National Imperatives for Earth and Climate Science Research and Applications Over the Next Decade.

ATTACHMENT 3

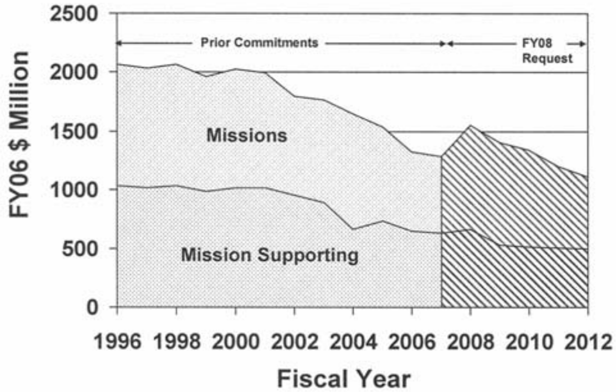

Figure 1: The NASA Earth Science Budget in constant FY 06 dollars (normalized for full-cost accounting across entire timescale; assumes 3%/year inflation from 2006 to 2012). Mission supporting activities include Earth Science Research, Applied Sciences, Education and Outreach, and Earth Science Technology.

Source: Testimony of Dr. Berrien Moore, III, at a Hearing of the Committee on Science and Technology, held on February 13, 2007 on National Imperatives for Earth and Climate Science Research and Applications Over the Next Decade.

ATTACHMENT 4

FY 08 NASA Budget Request - Earth Science

(Budget authority, $ in millions)	FY 2007	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012
EARTH SCIENCE	**1,464.5**	**1,497.3**	**1,545.8**	**1,520.1**	**1,411.2**	**1,353.2**
Earth Systematic Missions	523.8	606.1	693.0	576.0	387.9	387.9
Earth System Science Pathfinder	165.2	135.7	94.9	171.6	242.3	161.2
Earth Science Multi-Mission Operations	192.9	204.4	181.3	191.3	185.8	194.2
Earth Science Research	453.4	428.5	453.0	453.8	469.1	481.4
Applied Sciences	46.8	40.3	41.3	41.1	38.0	38.9
Education and Outreach	25.9	23.5	23.6	23.7	23.9	24.1
Earth Science Technology	56.6	58.9	58.7	62.6	64.2	65.5
Year to Year Increase		**2.2%**	**3.2%**	**-1.7%**	**-7.2%**	**-4.1%**

Chairman UDALL. To all who have joined us here for this very important hearing, I would like to make a short statement and I will turn to my good friend from Florida, Mr. Feeney, for his statement, and we will begin the hearing.

Today's hearing builds on the Science and Technology Committee's February 13 hearing at which we examined the findings and recommendations of the National Academy's Earth Science and Applications "Decadal Survey."

The Decadal Survey represented a consensus of the Earth sciences and applications community on what the Earth Science research priorities should be for the coming decade and identified a prioritized set of missions. It is an impressive report and it provides a very useful set of benchmarks for Congress as we attempt to evaluate NASA's current and planned activities in Earth science and applications.

Today we want to examine how well NASA's plans and programs compare to the priorities of the Decadal Survey and the extent to which NASA intends to support those priorities in the fiscal year 2008 budget and beyond. As numerous witnesses before this Committee have testified, the situation facing NASA's Earth Science program is not good.

To quote the Decadal Survey, it first noted that the Decadal Survey's interim report had cautioned that the Nation's system of environmental satellites was "at risk of collapse." It then went on to state that: "In the short period since the publication of the interim report, budgetary constraints and programmatic difficulties at NASA have greatly exacerbated this concern. At a time of unprecedented need, the Nation's Earth observation satellite programs, once the envy of the world, are in disarray."

Those are troubling words because NASA has a major role to play in the Nation's and indeed the world's climate research efforts. If NASA doesn't step up to that role, the negative consequences of that failure of leadership will be long-lasting.

I look forward to hearing from our NASA witness, Dr. Freilich, about what NASA is going to do to turn this worrisome situation around and I hope that he will be able to provide some specifics on how NASA intends to implement the Decadal Survey's recommendations.

In that regard, I am also concerned about the fate of the climate instruments from NPOESS, and the need to ensure that we don't needlessly disrupt the instrument development activities while the Administration is determining what will be done about them.

I hope that the good doctor will be able to shed some light today on what interim arrangements are being put in place to preserve those instrument teams and development efforts.

Finally, I think many of us in Congress are interested in ensuring that the Earth observations data being collected by NASA is applied wherever appropriate to societal needs. That is why I introduced the Remote Sensing Applications Act, which became Sections 313 and 314 of the *NASA Authorization Act of 2005.*

It is not clear that NASA's efforts to date have been fully responsive to the intent of that legislation and I look forward to working with the agency to make sure that the goals of the provisions can be realized.

Well, we have a lot of issues to address today, I again want to welcome our witnesses, and I look forward to your testimony.

[The prepared statement of Chairman Udall follows:]

PREPARED STATEMENT OF CHAIRMAN MARK UDALL

Good morning. I'd like to welcome our witnesses to today's hearing—we appreciate your participation.

Today's hearing builds on the Science and Technology Committee's February 13th hearing at which we examined the findings and recommendations of the National Academies' Earth Science and Applications "Decadal Survey."

The Decadal Survey represented a consensus of the Earth sciences and applications community on what the Earth Science research priorities should be for the coming decade, and it identified a prioritized set of missions. It is an impressive report, and it provides a very useful set of benchmarks for Congress as we attempt to evaluate NASA's current and planned activities in Earth science and applications.

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Well, we have a lot of issues to address today. I again want to welcome our witnesses, and I look forward to your testimony.

Chairman UDALL. At this time it is my privilege to recognize Mr. Feeney for whatever statement he may have.

Mr. FEENEY. Well, thank you, Chairman Udall.

This morning's hearing on NASA's Earth Sciences and Applications programs is the first held by our subcommittee on this important topic, and I would like to begin by thanking our witnesses for taking time from their busy schedules to join us today. I realize a tremendous amount of time, effort and preparation goes into appearances before Congressional committees, and I want all of our witnesses to know that this Committee greatly appreciates your efforts and values your wisdom.

Today's hearing on NASA's Earth Sciences and Applications programs and the fiscal year 2008 budget request gives our Committee an opportunity to review NASA's management of and rationale for its current array of Earth observing missions and an opportunity to understand how the agency will incorporate the recommendations of the Earth Sciences Decadal Survey in its future plans. NASA'S Earth Sciences program is one of that agency's unsung achievements. When discussing NASA, our nation's collective attention is often focused on human space flight or stunning images returned from distant planets and orbiting observatories. But rarely does the national press carry front-page stories or images from NASA's Earth-observing satellites except perhaps during hurricane season.

Having said that, most of the weather and climate-prediction tools used daily by forecasters is often a direct product of NASA-sponsored research. A good portion of climate change research is also made possible by data taken from NASA-developed sensors, satellites and sophisticated research analysis products. Will this record of accomplishment in Earth science missions continue? Yes. Will it happen fast enough to satisfy many of us and the research community? Probably not. Are NASA's plans for future Earth science research missions any indication of the agency's reduced commitment towards a robust program? Emphatically, no.

NASA's other science programs, astrophysics, planetary and heliophysics, share the same challenges as Earth science. The related Decadal Surveys prioritize researcher wishes and offer strategic guidance on the types and sequence of missions needed to answer leading questions. NASA has neither the resources nor oftentimes the necessary technologies to fill all of its desires but NASA does try to fulfill the highest priorities established by the research community. Requests for expanded efforts in all NASA's fields of endeavors simply confirm this agency's reputation as a place where the most challenging tasks get done.

Having said that, I hope we don't drift into an earlier era where NASA was tasked with doing too much with too little in the way of resources. We know where that path led, so I hope all NASA supporters, myself included, temper our enthusiastic desires with a realistic assessment of what is possible. NASA's Earth Science program has produced stunning scientific results often demonstrating for the first time measurements and capabilities that have never before been accomplished. I want that record of achievement to continue. It is also my desire that we build upon this program's success to enable the goals established in the Decadal Survey.

Again, thank you, Chairman Udall, and thanks again to the witnesses.

[The prepared statement of Mr. Feeney follows:]

PREPARED STATEMENT OF REPRESENTATIVE TOM FEENEY

Mr. Chairman, this morning's hearing on NASA's Earth Science and Applications Programs is the first held by our subcommittee on this important topic, and I'd like to begin by thanking our witnesses for taking time from their busy schedules to join us today. I realize a tremendous amount of time, effort and preparation goes into appearances before Congressional committees, and I want all of our witnesses to know that this committee greatly appreciates your efforts, and values your wisdom.

Today's hearing on NASA's Earth Sciences and Applications programs, and the FY08 budget request, gives our committee an opportunity to review NASA's management of—and rationale for—its current array of Earth-observing missions, and an opportunity to understand how the agency will incorporate the recommendations of the Earth Sciences Decadal Survey into its future plans.

NASA's Earth Sciences program is one of that agency's unsung achievements. When discussing NASA, our nation's collective attention is often focused on human space flight, or stunning images returned from distant planets and orbiting observatories. But rarely does the national press carry front-page stories or images taken from NASA's Earth-observing satellites, except perhaps, during hurricane season. Having said that, most of the weather and climate prediction tools used daily by forecasters is often a direct product of NASA-sponsored research. And a good portion of climate change research is also made possible by data taken from NASA-developed sensors, satellites, and sophisticated research and analysis products.

Will this record of accomplishment in Earth Science missions continue? Yes. Will it happen fast enough to satisfy the research community? Probably not. Are NASA's plans for future Earth Science research missions any indication of the agency's reduced commitment toward a robust program? Emphatically no.

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Requests for expanded efforts in all of NASA's fields of endeavor simply confirm this agency's reputation as a place where the most challenging of tasks get done. Having said that, I hope we don't drift into an earlier era where NASA was tasked with doing too much with too little. We know where that path led. So I hope all NASA supporters—myself included—temper our enthusiastic desires with a realistic assessment of what is possible.

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Thank you, Mr. Chairman. And my thanks again to our witnesses.

Chairman UDALL. I thank the gentleman from Florida.

At this point, if there are Members who wish to submit additional opening statements, your statements will be added to the record. Without objection, so ordered.

At this time I would like to recognize Ms. Hooley, who is going to introduce the first witness, Dr. Freilich. Congresswoman Hooley.

Ms. HOOLEY. Thank you, Mr. Chair, and I would like to thank not only you but our Ranking Member Feeney for allowing me to participate today and the opportunity to introduce Dr. Michael Freilich. Dr. Freilich is the Director of the Earth Science Division in the Science Mission Directorate at NASA Headquarters. Prior to coming east to work for NASA, he was a Professor and Associate Dean in the College of Oceanic and Atmospheric Sciences at Oregon State University, which is in my district. I am sure that he is just as proud as I that the Oregon State University's baseball team just won its second national championship in as many years.

Dr. Freilich's research focuses on the determination, validation and geophysical analysis of ocean surface wind velocity measured by satellite-borne microwave radar and radiometer instruments. He has developed scatterometer and altimeter wind model functions as well as innovated validation techniques for accurately quantifying the accuracy of space-borne environmental measurements. Thank you, Dr. Freilich, for agreeing to testify before this committee. I am sure the Committee will benefit from your insights, and I would like to state that I have a markup in another committee going on at the same time so I will have to leave, but we are so glad you are here. Thank you for coming.

Chairman UDALL. I thank the gentlelady for that introduction and I would like to at this time introduce the rest of the panelists. I will start with Dr. Richard Anthes, who is appearing before this committee for the second time after testifying on the National Academy's Earth Science Decadal Survey back in February. We appreciate his willingness to participate in today's hearing. You all should know he is President of the University Corporation for Atmospheric Research, and I am biased. It is also great to have another Coloradoan here in the Nation's capital, so Doctor, thank you for making the trip here.

Next to Dr. Anthes is Dr. Eric Barron, who is the Dean of the Jackson School of Geosciences at the University of Texas, Austin, and he was the Chair of Climate Variability and Change Panel of the Decadal Survey Committee, and this is not his first appearance before this committee. Dr. Barron, thank you for being here today.

And finally, we have Dr. Timothy Foresman, who is the President for the International Center for Remote Sensing Education and has long been involved in activities related to promoting the application of Earth science data that meets societal needs. Again, welcome.

I think all of you know, you are pros, you have been here before but we ask you to limit your spoken testimony to five minutes and then after which we will have a interchange in which Members of the Subcommittee will have five minutes each to ask questions.

Dr. Freilich, we will start with you. The floor is yours.

STATEMENT OF DR. MICHAEL H. FREILICH, DIRECTOR, EARTH SCIENCE DIVISION, SCIENCE MISSION DIRECTORATE, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA)

Dr. FREILICH. Thank you very much. Mr. Chairman and Subcommittee Members, thank you for the opportunity to discuss the President's fiscal year 2008 budget request for NASA's Earth Science program. NASA is committed to Earth science, as am I. The budget request includes nearly $1.5 billion for Earth science, an increase of about $32 million over the fiscal year 2007 request. Our balanced program includes flight missions, research investigations, applied science, technology investment and outreach programs. I will focus my remaining oral comments on your specific questions.

First, our top Earth science objectives and plans. Our primary objective is to advance Earth systems science and to use this understanding sufficiently to address societal issues. To reach this goal, we will in priority order first reinvigorate the flight portfolio by building and launching seven missions now under development and initiating new missions as recommended by the Decadal Survey. Second, we are working with NOAA and other agencies to hasten transition processes so that measurements pioneered and proved by NASA will be acquired by operational satellite systems over multi-decadal periods. And third, we will preserve and expand through competitive solicitations the preeminent research and analysis, applied sciences, technology development and educational programs that distinguish the NASA Earth science endeavor. The Decadal Survey provides specific guidance in these areas and the

President's 2008 budget request advances us towards these objectives.

You asked about balance in the Earth Sciences program. The program is nicely balanced between flight and research science activities with almost half the total allocated to our 14 operating missions and the seven missions in development and the other half to research applied sciences, data systems, technology development and education program. The Earth Science Subcommittee of the NASA Advisory Council annually examines the split of activities and assesses our scientific performance. Regarding mission size, all of the missions now in development and those recommended by the Decadal Survey are focused missions. We are not planning large future observatories such as the presently orbiting Terra Aqua and Aura platforms.

Our plan and timetable for implementing the Decadal Survey: our selection of Earth observing missions to be flown in the next 10 to 15 years is guided by the Decadal Survey's science priorities. We take the Decadal Survey's recommendations seriously. Indeed, the 2008 budget request addresses the flight recommendation of the NRC's 2005 interim report by including funding for the key precursor missions highlighted in that report. Now, the final Decadal Survey arrived too late to influence the fiscal year 2008 budget but its recommendations are being used in development of the fiscal year 2009 budget request.

Since the survey came out in early 2007, we have been vigorously pursuing activities in four areas. First, we have undertaken studies of each of the recommended missions to understand in detail the technical challenges and full costs including the science so that we can assemble and implement a realistic program. We are conducting community workshops to understand the capabilities of the missions as recommended, to optimize the intended scientific return and to define the other measurements that must be acquired in order for the scientific goals to be achieved. The first of these workshops, which is focused on ICESat—II, is actually happening this week as we speak near BWI. We have engaged our international partners. In the past two months alone, I have had eight productive multi-day discussions with partner space agencies in order to identify common interests and complementary expertise so that we can implement the Decadal Survey in a coordinated way. We are establishing joint working groups for future mission collaboration studies with the French, Japanese, German, Canadian and European space agencies, in all cases building on successful existing and past collaboration.

NASA is also playing a leading role in supporting the international Committee on Earth Observing Satellites, CEOS, which coordinates satellite systems for the international Group on Earth Observations, GEO. Finally, as planned, we are revising the Earth Science Division chapter in the SMD Science Plan to reflect the missions and the scientific priorities identified in the Decadal Survey. This revision will be reviewed by the NRC and the Advisory Council in the early fall timeframe.

Finally, research to operations transitions and applications. NASA is working closely with other federal agencies, in particular NOAA and USGS, to transition research capabilities to long-term operations as the technologies are demonstrated. We have prepared the first NASA–NOAA report highlighting our fiscal year 2008 joint activity plan as required by the 2005 *NASA Authorization Act.* NASA and NOAA working with OSTP are conducting joint studies of the impacts and mitigation strategy in response to the Nunn-McCurdy refocusing of the NPOESS program. The Applied Sciences program accelerates the broader use of NASA Earth science research results by partnering with other organizations in pilot projects to demonstrate how NASA results can improve decision-making and resource management. In many cases, the demonstrated improvements continue to be used by our partners even after the NASA Applied Sciences project ends, and we can talk about specific examples of that. We have identified an Applied Sciences representative for each Earth Science mission in operation and in development in order to assure rapid and efficient identification of applications potential.

So in summary, it will require several budget cycles to implement a program derived from the Decadal Survey's thoughtful and comprehensive recommendations. I would like to end by deeply thanking the Decadal Survey committee members. NASA's commitment to Earth science research is commensurate with theirs. Thank you.

[The prepared statement of Dr. Freilich follows:]

PREPARED STATEMENT OF MICHAEL H. FREILICH

Mr. Chairman and Members of the Subcommittee, thank you for the opportunity to appear today to discuss the President's FY 2008 budget request for NASA's Earth Science program. You have previously heard from the new Associate Administrator for the Science Mission Directorate (SMD), Alan Stern, on his general plans for the entire Directorate, in particular in the area of Space Science, and I welcome this opportunity to discuss specifically the important area of Earth Science, especially in light of the recently released National Research Council's (NRC's) Earth Science Decadal Survey.

In your letter of invitation, you asked that I address my priorities for the Earth science program in the coming years, as well as the plan for meeting these objectives. My primary objective for the Earth Science Division is to expand the leading role of NASA measurements and NASA-supported analyses in advancing Earth System science—improving our quantitative understanding of the Earth as an integrated system. To reach this goal, we will reinvigorate the flight portfolio by soliciting, implementing, launching, and operating new cutting-edge flight missions; we will work with the National Oceanic and Atmospheric Administration (NOAA) and other national and international operational agencies to hasten transition processes so that measurements pioneered and proved by NASA will be subsequently acquired by operational satellite systems over the multi-decadal periods required to detect climate signals; and we will preserve and expand the preeminent research and analysis, applied sciences, technology development, and educational programs that distinguish the NASA Earth Science endeavor. The recently released NRC's Earth Science Decadal Survey provides specific guidance in these areas, and the FY 2008 budget request along with planned interagency and international working group activities will allow us to advance toward these objectives.

NASA's FY 2008 budget request includes $1.5 billion for the study of planet Earth from space. This represents an increase of $32.8 million over the FY 2007 budget request (adjusted for full-cost simplification and the new theme structure of the budget). The FY 2008 request will fund a wide-ranging and balanced program of activities, including:

- Developing, launching, and operating Earth-observing space missions;
- Competitively selecting and pursuing research and analysis science investigations conducted by NASA and non-NASA researchers;

- Conducting Applied Science projects that help other federal and regional agencies and organizations to efficiently use products from NASA Earth research to advance their missions;
- Soliciting and advancing technology development efforts to enable the missions of the future; and,
- Providing education and public outreach programs to make our knowledge of the Earth accessible to the world.

NASA's budget request supports a balanced program, allocating over 30 percent of NASA's request for the Science Mission Directorate and, within the Science Mission Directorate, allocating 27 percent of funding for Earth Science.

Much of the science community's present state of knowledge about global change—including many of the measurements and a significant fraction of the analyses which serve as the foundation for the recent report of the Intergovernmental Panel on Climate Change (IPCC)—is derived from NASA's Earth Science program. For example, using data from Earth observing satellites NASA-supported researchers are: monitoring ice cover and ice sheet motions in the Arctic and the Antarctic; quantifying the short-term and long-term changes to the Earth's protective shield of stratospheric ozone, including the positive impacts of the Montreal protocols; discovering robust relationships between increasing upper ocean temperature and decreasing primary production from the phytoplankton that form the base of the oceans' food chain; and, using a fleet of satellites flying in formation (the "A-Train"), making unique, global, near-simultaneous measurements of aerosols, clouds, temperature and relative humidity profiles, and radiative fluxes.

Our improved understanding of Earth System processes leads to improvements in sophisticated weather and climate models, which, in turn—when initialized using the satellite data—can be used to predict natural and human-caused changes in the Earth's environment over time scales of hours to years.

Importantly, near-real-time measurements from NASA research missions (including the Tropical Rainfall Mapping Mission (TRMM), the Quick Scatterometer (QuikSCAT), the Atmospheric Infrared Sounder instrument on the Aqua mission, and others) are used routinely by NOAA and other U.S. and international agencies to improve weather forecasting. Similarly, high quality measurements obtained by NOAA's operational weather satellites provide essential context for the scientific analyses of the NASA research mission data. There is thus a strong synergy between our nation's research satellites and our operational space-borne systems. NASA works closely with the other Federal agencies—specifically NOAA—responsible for forecasting to transition these research capabilities to long-term operations as the technologies are demonstrated and matured. As we speak, NASA is operating 14 Earth observing missions. Five more missions are quite far advanced in their development, and will be launched in 2008 and 2009. Of these, the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP) and the Ocean Surface Topography Mission (OSTM) will continue critical Earth System and climate measurements that were initiated by the Earth Observing System (for NPP) and the TOPEX/Poseidon and JASON–1 missions (for OSTM). The Glory mission will fly an instrument to extend our measurements of total solar irradiance, as well as an instrument that will provide unique, first-ever measurements of properties of atmospheric aerosols. The Orbiting Carbon Observatory (OCO) and the Aquarius mission will make new, first-of-a-kind global measurements of atmospheric carbon dioxide concentrations and ocean surface salinity—both parameters of known importance to the study of climate change.

The FY 2008 budget request also funds the reconstituted Landsat Data Continuity Mission (LDCM) for launch in 2011. I am pleased to report that the procurement activities for the LDCM are on track. We recently announced the selection of four contractors to study how their spacecraft could accommodate the LDCM Operational Land Imager instrument. Final results are expected this fall. The FY 2008 budget funds the Global Precipitation Measurement Mission (GPM) for launch of its Core spacecraft not later than 2013, followed a year later by launch of the NASA GPM Constellation spacecraft. Extending the pioneering rain measurements initiated with the joint U.S./Japanese TRMM and providing a calibration standard for several other rain-measuring instruments orbited by others, the GPM mission will provide us with accurate, global rain measurements every three hours—much more frequently than is currently possible. Knowledge of accurate rainfall rates and atmospheric water quantities is essential for the study of the Earth's hydrologic cycle and its sensitivity to climate change. In addition, the GPM measurements will be used by operational weather prediction agencies around the globe to improve weather forecasts and severe storm predictions.

As a complement to the research and analysis activities which improve our understanding of the Earth system, the Applied Sciences Program evaluates NASA Earth science data, results, and technology for their potential to serve society beyond their original scientific purpose. Where appropriate, the program accelerates the broader use of these Earth science research results by partnering with federal agencies and other organizations to test whether NASA results can improve decision-making and resource management. In many cases, the demonstrated improvements continue to be used by our partners in their operational decision support systems, after the NASA Applied Sciences project ends.

We have had many recent successes across a broad range of societal benefit areas. I will touch here on examples in the areas of air transportation, regional environmental management, and natural disasters. NASA is working in partnership with the Federal Aviation Administration, NOAA's National Weather Service, and the National Center for Atmospheric Research to ensure safe and efficient air travel for the American public through enhancements to aviation weather forecasting. Weather is a contributing factor in approximately 30 percent of all aviation accidents and accounts for over 60 percent of all delays experienced in the air transportation system. Weather delays in air travel cost the American public over $4 billion per year. By incorporating new, NASA-developed algorithms, observations, and predictive capabilities into aviation weather forecasts, more accurate, dependable, and useful forecasts of threats to aviation including icing, turbulence, convection, and volcanic ash can be made. For example, NASA recently released results that suggest the incorporation of improved satellite observations and new algorithms into a decision support tool for thunderstorm initiation often enhance performance by providing a detailed analysis of the locations and early growth of non-precipitating convective clouds. One newly developed parameter showed an 84 percent probability of detection of convective initiation over a thirty minute window.

In terms of improving regional environmental management with techniques deployable both in the United States and abroad, NASA is partnering with U.S. Agency for International Development and other U.S. and Latin American government agencies and nongovernmental organizations to develop, operate, and refine an environmental monitoring and visualization system for the entire isthmus of Central America. Known as SERVIR, this system is web-based and provides satellite- and ground-based geospatial data for management and decision support. In addition to a data archive, Internet mapping tools, and visualization software, SERVIR offers a number of decision support products including those for fires, floods, harmful red tide events, developing climate scenarios, and weather forecasting. Examples of recent activities are the use of SERVIR imagery by fire fighters in northern Guatemala to battle fires and national park managers in Belize employing SERVIR fire alerts to detect unauthorized incursions and clearing of tropical forest within the Chiquibul National Park. The SERVIR web location is *http://servir.net/*.

Another recent NASA Applied Science program contribution was our real-time support to state emergency responders in the Esperanza fires last October in California. A data integration tool developed under Applied Science's Wildfire Research and Applications Partnership or WRAP (NASA, USFS and the National Interagency Fire Center), together with a 16-hour emergency flight of a NASA Ames UAS (Unmanned Aerial System), provided invaluable real-time information about fire location, intensity, and extent that was used to guide the California Governor's Office of Emergency Services and the Esperanza Fire Incident Command Center as they battled the fire. The WRAP integration tool incorporates data and technology from an array of sources, both public and private, and displays the data on a Google Earth software base. In collaboration with the U.S. Forest Service, the WRAP project continues to be supported by the Earth Science Division's Research and Analysis and Technology Programs to further test the integrated UAS system during actual wildfire events this coming fire season in California.

In March, 2007, the NASA Administrator submitted to Congress the report on the Applied Sciences Program's planning, selection, and review processes in Accordance with Section 307 of the *National Aeronautics and Space Administration Authorization Act of 2005* (P.L. 109–155) ("the Act"). In this year's Research Opportunities in Space and Earth Sciences (ROSES) research announcement, we explicitly incorporated the requirements of Section 313 of the Act, which identifies the need to address State, local, regional and tribal agency needs and to utilize both NASA and commercial sector capabilities. Specifically, the Applied Sciences Program requires grantees to utilize commercially available products whenever it is appropriate and available, consistent with NASA Earth science policy. The Applied Sciences Program, under new leadership, is planning a comprehensive review of the program to ensure that it is aligned with the NAS Decadal Survey recommendations and is working with NASA leadership to establish an appropriate advisory structure, in accordance with Section 314 of the Act.

Even as we are acquiring and analyzing measurements today, we are planning the satellites, field experiments, scientific investigations, and Earth System models of the future. The recently released Earth Science Decadal Survey provides, for the first time, a scientifically based, community consensus statement of the top priority future Earth System Science problems to be addressed, and it suggests a sequence of notional missions whose measurements could contribute to advancing our understanding of the Earth and its environment.

We welcome the Decadal Survey—indeed, we asked for it. NASA, along with NOAA and the U.S. Geological Survey (USGS), requested and funded the NRC to conduct this first Decadal Survey in Earth science. We formally made the request in the fall of 2003 and the study began in earnest in 2004. The massive undertaking was only completed this January. We are grateful for all of the efforts of the Co-Chairs and NRC staff, the members of the decadal survey Executive Committee, and the literally hundreds of Earth Science researchers who volunteered their time and their ideas. Their success in creating a broad consensus is a substantial achievement.

The science priorities identified by the Decadal Survey will be our primary guide as we design and select Earth observing missions to be flown in the next 10–15 years. In the space sciences, NASA has a long history of guidance by NRC decadal surveys. Indeed, even in the Earth sciences, where this is the first Decadal Survey, the President's FY 2008 budget request for NASA was guided by recommendations included in the interim report issued by the Decadal Survey committee in 2005. The FY 2008 budget request includes funding and predictable launch dates for the LDCM, the Glory aerosol and solar irradiance mission, NPP, and GPM, all of which figured strongly in the interim report.

Unfortunately, the full Decadal Survey arrived too late for its specific recommendations to influence the FY 2008 budget process, but its scientific priorities will be used in development of the FY 2009 and subsequent budget requests. NASA's FY 2008 budget request also includes funding for an additional, competed flight mission, which will launch sometime around 2014. We will be guided by the Decadal Survey as we choose the scientific focus and instrument complement for this mission, starting with a competitive solicitation in late 2008.

In addition to its science priorities and the notional mission set, the Decadal Survey provides several recommendations relevant to the design and implementation of the Earth Science flight program. Survey recommendations in the areas of international collaboration and technology investment deserve particular consideration.

We all recognize that a constellation of missions and many simultaneous measurements—such as those obtained by the A-train spacecraft described above—are needed to understand the interactions between Earth system processes. No agency or nation can afford to develop and fly all necessary missions single handedly.

The Decadal Survey emphatically recommends international collaboration, to maximize humankind's benefits from our net investment in Earth science, and to avoid unnecessary duplication. To this end, we have already begun discussions with our closest international space agency partners: the Canadian, European, French, Japanese, and German space agencies. Throughout the spring and early summer, we held eight substantive bilateral meetings with international space agency partners to identify and refine areas of common interest and complementary expertise. We are also actively engaged—indeed NASA and the United States are leaders—in international coordination bodies such as the Committee on Earth Observation Satellites (CEOS) and the international Group on Earth Observations (GEO). As with our present OSTM, Aquarius, and GPM missions, we anticipate substantial joint projects with international partners as we construct missions to address the Decadal Survey's science questions. As a result of this Spring's activities, we are establishing several bilateral, focused, technical-level working groups to refine science investigations, measurement techniques, and programmatic collaboration approaches for some early- and mid-term Decadal Survey missions where clear partner interest and expertise exists.

NASA works closely with other federal agencies to support an integrated federal program of climate research. As noted above, the Decadal Survey was jointly requested by NASA, NOAA and the USGS and assigns some priority missions to NASA, and some to NOAA for execution. NASA's contribution to the U.S. Climate Change Science Program (CCSP) is unchanged from the FY 2007 to FY 2008 budget request, and remains the largest single contribution to the Program. Consistent with the *Space Act* and the 2005 *NASA Authorization Act,* NASA's role within the broader federal program is guided by the U.S. National Space Policy, authorized by the President in August, 2006. In particular, NASA works closely with NOAA to transition mature and proven measurement capabilities to long-term operations.

Science-driven technology investment is one of the keys to the design and implementation of any future mission set. It is essential to have the technology developed and tested in a relevant environment prior to the approval of any mission. This helps to avoid cost overruns that occur when problems arise with a new technology late in the mission development cycle. To foster advanced technologies for Earth science, NASA's strategy is two pronged, as recommended by the Decadal Survey, with both focused technology and core technology elements.

Where we know the missions we want to implement and what new technologies are required on a certain schedule, we make focused investments to assure technologies are available when we issue competitive solicitations for mission formulation and development. This is done through the highly successful Instrument Incubator Program, funded under the Earth Science Technology Office, which matures instrument technologies for future measurements.

The second prong addresses the seed corn or "core technologies," for advanced Earth observing missions of the future. Where we know that certain classes of technologies are needed for the types of measurements we would like to make in the future, or are simply convinced that investment in certain sensor or detector technology areas will yield fruit, we will issue open, competitive solicitations for the best ideas. Examples include advanced component development (which allows scientists and technologists to take an idea from the concept to the bench top demonstration stage), laser risk reduction (which has developed fundamental lidar technologies applicable to multiple NASA missions), and advanced information systems technology development (which provides advanced operations technologies which aid in reducing future mission costs).

The Decadal Survey, the U.S. Climate Change Science Program, and NASA's own planning in Earth science all assume the presence of an operational system of environmental monitoring satellites that can make climate-quality measurements. The Nation needs such a system. That is why NASA, along with NOAA and the Air Force, is a member of the NPOESS governing body, and why NASA entered into a partnership with the NPOESS Integrated Program Office to develop NPP. NPP is designed both to continue essential measurements from NASA's Earth Observing System satellites as well as provide a demonstration of instruments to be flown on NPOESS.

The Nunn-McCurdy certified NPOESS program, as you are aware, focuses NPOESS on its weather mission and deletes many of the capabilities previously planned for climate science. As the Decadal Survey committee was finalizing its notional mission set and sequence, the full impact of the removal of the climate sensors from the NPOESS program was just coming to light. Since last summer, we in NASA have been working closely with NOAA, OSTP, and the scientific research community to understand and rank the impacts of these programmatic perturbations, and to develop realistic mitigation scenarios for the most important measurements. This is being done on an accelerated schedule to inform the development of the FY 2009 budget request. In addition to our agency-based technical evaluations and preliminary mitigation strategy designs, NASA and NOAA commissioned, supported, and participated in an NRC workshop which was held last week after several weeks of community planning (including members of the original Decadal Survey committee). The workshop was chartered to examine the scientific and research-focused impacts of the programmatic changes to NPOESS and to consider various recovery scenarios. We are eagerly awaiting the workshop report, expected later in the summer, again in time to provide recommendations useful for helping to determine the FY 2009 budget.

I am pleased to report that, in an initial step, NASA and NOAA have agreed to share equally the cost to restore the Ozone Mapping and Profiler Suite (OMPS)-Limb to the NPP satellite set to launch in 2009. The OMPS Limb will measure the vertical distribution of ozone and complements existing NPOESS systems, in particular the OMPS-Nadir instrument, which continues the long global time series of total column ozone. The first-ever combination of total and vertically resolved ozone measurements will provide scientists unique insight into the dynamical and chemical processes which regulate atmospheric composition.

Considering both the guidance from the Decadal Survey and the realities of the recent programmatic changes to NPOESS, NASA is proceeding with a mission planning activity to determine the focus and content of our specific future Earth observing missions. The plan will integrate the scientific recommendations and priority/sequence of the Decadal Survey, the joint and ongoing NASA–NOAA and community examinations of the NPOESS Nunn-McCurdy changes, and the contributions of our international partners. Through a series of concept studies conducted at

NASA Centers, we are carefully examining the Decadal Survey's notional missions. The studies are assessing the technological readiness, system engineering challenges, and expected costs (including support for scientific validation and analysis of the mission data) of each notional mission. These concept studies are accessing the full capability of the NASA mission design and costing apparatus, to complement the estimates assigned by the NRC. We have organized and broadly announced four community workshops, one for each of the four early-term missions assigned to NASA in the NRC's Decadal Survey. The two aims of each workshop are to define the full range of scientific capabilities of each of the synthesized missions recommended by the Decadal Survey, and to identify essential contextual measurements that must also be present in order to advance the science priorities identified in the Decadal Survey. The workshops should provide great community insight into, and recommendations for, these early missions and will aid the subsequent detailed mission design work. These first four workshops will be held during late June and through July—indeed, the workshop focused on the notional "IceSat-II" mission is being held near Baltimore yesterday, today, and tomorrow. As our NASA planning evolves, community involvement will be assured through many more workshops, regular interactions with the Earth Science Subcommittee of the NASA Advisory Council, as well as discipline- and science-focus theme working groups which regularly inform our plans and examine our progress within the NASA Earth Science Division.

The planning process also includes an update later this year to the NASA Earth Science Plan. Indeed, when the Congress asked the Agency for a Science Plan in the *NASA Authorization Act of 2005* (P.L. 109–155), you recognized that the Decadal Survey would not be available in time to influence the Earth Science portion of that Plan. Therefore, NASA was asked to describe how it might revise that Plan based on the Earth Science Decadal Survey. Our planning activity and the Science Plan will address that question. We have developed and are presently examining a draft of the Science Plan changes, and expect to begin vetting a refined version through the NRC and NASA Advisory Council committees by the September time frame.

While the scope and specificity of the planning activity clearly must exceed that of the Decadal Survey and must accommodate issues of programmatic balance and national needs, it is definitively not our intention to redo the Decadal Survey or to change the scientific priorities that it identified.

As with decadal surveys in other parts of the Science Mission Directorate portfolio, this Decadal Survey is only the starting point. However, Earth Science planning is even more complex than in other divisions, given the web of partnerships, the many and diverse users of Earth science data, and its societal impact. Considering the long time horizon in the NRC's report, it will require several budget cycles to implement the program that we will derive from the Decadal Survey's near- and mid-term recommended mission sets. Nevertheless, our planning process starts with the consensus scientific priorities articulated for us by the NRC. So I will close by reiterating my gratitude to the Decadal Survey committee Co-Chairs and members for their excellent work. NASA's commitment to Earth Science research is commensurate with theirs.

I welcome your questions on NASA's Earth science program.

Table 1

NASA Earth Science Missions Currently in Development

NPOESS Preparatory Project (2009) Strategic mission; Systematic measurement	Ensures continuity of several key climate measurements between the Earth Observing System and NPOESS. Implementation of the NPOESS Presidential Decision Directive of 1994. Joint mission with the NPOESS Integrated Program Office.
Landsat Data Continuity Mission (2011) Strategic mission; Systematic measurement	Ensures continuity of long-term global land cover change data. Post-LDCM land imagery acquisition by an operational agency is planned. Joint mission with USGS.
Ocean Surface Topography Mission (2008) Strategic mission; Systematic measurement	Ensures continuity of ocean altimetry data; planned as part of a transition to operational agencies. Joint mission with NOAA, CNES & EUMETSAT.
Glory (2008) Strategic mission; Initializes a systematic measurement	Addresses high priority objective of the U.S. Climate Change Science Program. Measure global aerosols & liquid cloud properties and solar radiation. Mandated by the Presidential Climate Change Research Initiative of 2001.
Orbiting Carbon Observatory (2008) Competed mission; Earth System Science Pathfinder	Nearing completion of development. First global measurement of CO_2 from space; small Earth science mission.
Aquarius (2009) Competed mission; Earth System Science Pathfinder	In advanced stage of development. First global measurement of sea surface salinity from space; small Earth science mission. Joint mission with Argentina.
Global Precipitation Measurement (2013) Strategic mission - Initializes a systematic measurement	Recommended by 2005 interim report of decadal survey committee; extend spatial coverage to global and temporal coverage to every 3 hours with constellation
Earth System Science Pathfinder; TBD (2014) Competed mission	*Focus and relative priority to be determined using decadal survey;* solicitation no earlier than 2008 for 2014 launch.

BIOGRAPHY FOR MICHAEL H. FREILICH

Michael H. Freilich is the Director of the Earth Science Division, in the Science Mission Directorate at NASA Headquarters. Prior to coming to NASA, he was a Professor and Associate Dean in the College of Oceanic and Atmospheric Sciences at Oregon State University. He received BS degrees in Physics (Honors) and Chemistry from Haverford College in 1975 and a Ph.D. in Oceanography from Scripps Institution of Oceanography (Univ. of California, San Diego) in 1982. From 1983–1991 he was a Member of the Technical Staff at the Jet Propulsion Laboratory.

Dr. Freilich's research focuses on the determination, validation, and geophysical analysis of ocean surface wind velocity measured by satellite-borne microwave radar and radiometer instruments. He has developed scatterometer and altimeter wind model functions, as well as innovative validation techniques for accurately quantifying the accuracy of space-borne environmental measurements.

Dr. Freilich served as the NSCAT Project Scientist from 1983–1991 and as the Mission Principal Investigator for NSCAT from 1992–1997. Until he relinquished his project posts to join NASA HQ, he was the Mission PI for QuikSCAT (launched in June, 1999) and SeaWinds/ADEOS–2 (launched in December, 2002). He was the team leader of the NASA Ocean Vector Winds Science Team and is a member of the QuikSCAT, SeaWinds, and Terra/AMSR Validation Teams, as well as the NASDA (Japanese Space Agency) ADEOS–2 Science Team.

Dr. Freilich has served on many NASA, National Research Council (NRC), and research community advisory and steering groups, including the WOCE Science Steering Committee, the NASA EOS Science Executive Committee, the NRC Ocean Studies Board, and several NASA data system review committees. He chaired the NRC Committee on Earth Studies, and served on the NRC Space Studies Board and the Committee on NASA/NOAA Transition from Research to Operations.

His honors include the JPL Director's Research Achievement Award (1988), the NASA Public Service Medal (1999), and the American Meteorological Society's Verner E. Suomi Award (2004), as well as several NASA Group Achievement awards. Freilich was named a Fellow of the American Meteorological Society in 2004.

Freilich's non-scientific passions include nature photography and soccer refereeing at the youth, high school, and adult levels.

Chairman UDALL. Thank you, Dr. Freilich.

Dr. Anthes, the floor is yours.

STATEMENT OF DR. RICHARD A. ANTHES, PRESIDENT, UNIVERSITY CORPORATION FOR ATMOSPHERIC RESEARCH; CO–CHAIR, COMMITTEE ON EARTH SCIENCE AND APPLICATIONS FROM SPACE, NATIONAL RESEARCH COUNCIL, THE NATIONAL ACADEMIES

Dr. ANTHES. Mr. Chairman and Ranking Minority Member and Members of the Committee, thank you for inviting me to testify today. As Mr. Udall said, I am President of UCAR, the University Corporation for Atmospheric Research, and I have to be careful because the gentleman to my left is going to be probably the next Chairman of the UCAR board of trustees, so I have to be nice to him and to the State of Texas.

Before I get into my prepared remarks, I would just like to remind us that the news of the last few days about the terrible fires in the Lake Tahoe area following the winter of only about 30 percent normal snowfall there, the droughts in the West, the droughts in the Southeast where some places in Florida and Georgia are 12 feet below normal in rainfall, is all consistent with the kind of changes that we are worried about as the climate warms in the United States and the rest of the world. So the observations that we are talking about in the Decadal Survey as we said are more important than ever. This is not the time to be cutting back on observation of the Earth. It is time to be augmenting them.

The NRC report recommends a path forward that establishes U.S. leadership in Earth science and applications to avert the potential collapse of the U.S. system of environmental satellites. This can be accomplished in a fiscally responsible manner. The cost is very small in comparison to the societal needs and benefits.

Mr. Chairman, you asked me for my views on the top three priorities for NASA's Earth Science program during the next five years. The highest priority is that NASA commit to and begin to implement its recommended decadal missions. Starts on the initial seven missions should begin in 2008. The second priority is that NASA increase its suborbital capabilities. NASA'S airborne programs have suffered substantial diminution and should be restored. Both conventional and unmanned aircraft are needed for instrument development, technology advancement and for their direct contribution to Earth observations. The third priority is that NASA restore support of its research and analysis programs and efforts in Earth system modeling. Improved information about potential future changes in climate, weather and other environmental conditions will come from better observations but also more capable models of the Earth system and a vigorous research program to use the observations in models and interpret the results.

This committee's leadership on Earth sciences and the recent actions in the House appropriations process with respect to the fiscal year 2008 budget are encouraging and greatly appreciated, but even with the increase in NASA's Earth Science request for 2008, funding falls short of what is needed to get a full start on the recommended program, as you can see by this visual which shows the actual NASA budget starting in 1996 going through the actual budget in 2006 and 2007 and then projected budget or requested budget in 2008 and to run out beyond that. You can see that despite the encouraging upward turn for 2008, the gap between what is needed to complete and execute our Decadal Survey and what it is in the run-out from the 2008 request increases every year. The other point to make from this graph is that the funds to implement the Decadal Survey are only restoring the NASA Earth Science budget and real purchasing power to what it was in the last part of the previous century and the early part of this one. So we did a very strong prioritization to get a recommended set of missions that we considered minimal to meet the needs and not one that would bust the budget.

You also asked about international partnerships, and Dr. Freilich made some very encouraging remarks in that direction a few minutes ago. I would like to mention the collaborations with other nations not only saves scarce resources for all partners but promote scientific collaboration and sharing of ideas among the many talented people of all nations. However, they can come at a cost. The success of a partnership depends on both partners meeting their commitments, and if one partner runs into funding problems or technological difficulties, it can threaten the whole mission.

I would like to close my testimony with a quote from Vice Admiral Richard H. Truly, former NASA Administrator, Shuttle astronaut and the first commander of the Naval Space Command in a recent report, National Security and the Threat of Climate Change. Describing his experience in space 25 years ago, Admiral Truly said, "I have imager burned in my mind that will never go away, images of the Earth and its fragility. I was a test pilot. I was an aviator. I was not an environmentalist. When you look at the Earth's horizon, you see an incredibly beautiful but very thin line. That thin line is our atmosphere, and the real fragility of our atmosphere is that there is so little of it. The stresses that climate change will put on our national security will be different from any we have ever dealt with in the past. For one thing, unlike the challenges we are used to dealing with, these will come upon us extremely slowly, but come they will and they will be grinding and inexorable." Admiral Truly said he was not convinced of the importance of climate change by any person or interest group; he was convinced by the data. We as a nation must continue to provide the data on Earth for only the data can reveal the truth that will affect us all.

Thank you very much.

[The prepared statement of Dr. Anthes follows:]

PREPARED STATEMENT OF RICHARD A. ANTHES

Mr. Chairman, Ranking Minority Member Calvert, and Members of the Subcommittee: thank you for inviting me to testify on this important subject. My name is Richard Anthes, and I am the President of the University Corporation for Atmospheric Research (UCAR), a consortium of 70 research universities that manages the National Center for Atmospheric Research, on behalf of the National Science Foundation, and additional scientific education, training and support programs. I am also the current President of the American Meteorological Society. 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.

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 recently completed a "decadal survey" of Earth science and applications from space. ("Decadal surveys" are the 10-year prioritized roadmaps that the NRC has done for 40 years for the astronomers; this is the first time it is being done for Earth science and applications from space.) Among the key tasks in the charge to the decadal survey committee were 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 an extensive report in response to this charge. Over 100 leaders in the Earth science community participated on the survey steering committee or its seven study panels. It is noteworthy that this was the first Earth science decadal survey, and the committee and panel members did an excellent job in fulfilling the charge and establishing a consensus—a task many previously considered impossible. A pre-publication version of the report was published in January 2007 and is available at *www.nap.edu/catalog/11820.html*; the final version will be published later this year.

The committee's vision is encapsulated in the following declaration, first stated in the committee's interim report, published in 2005:

> *Understanding the complex, changing planet on which we live, how it supports life, and how human activities affect its ability to do so in the future is one of the greatest intellectual challenges facing humanity. It is also one of the most important challenges for society as it seeks to achieve prosperity, health, and sustainability.*

As detailed in the committee's final report, and as we were forcefully reminded by the latest set of reports from the International Panel on Climate Change (IPCC), the world faces significant and profound environmental challenges: shortages of clean and accessible freshwater, degradation of terrestrial and aquatic ecosystems, increases in soil erosion, changes in the chemistry of the atmosphere, declines in fisheries, and above all the rapid pace of substantial changes in climate. These changes are not isolated; they interact with each other and with natural variability in complex ways that cascade through the environment across local, regional, and global scales. Addressing these societal challenges requires that we confront key scientific questions related to ice sheets and sea level change, large-scale and persistent shifts in precipitation and water availability, transcontinental air pollution, shifts in ecosystem structure and function, impacts of climate change on human health, and occurrence of extreme events, such as hurricanes, floods and droughts, heat waves, earthquakes, and volcanic eruptions.

As a result, one way or the other, our international neighbors and we will undoubtedly be taking steps in an effort to deal with the climate changes we will confront. And as we do so, policy-makers and others will want to know if such steps are actually making a difference in addressing climate change. Yet at a time when the need for that kind of information has never been greater, we are faced with an Earth observation program that will dramatically diminish in capability over the next 10–15 years.

Between 2006 and the end of the decade, the number of operating missions will decrease dramatically and the number of operating sensors and instruments on NASA spacecraft, most of which are well past their nominal lifetimes, will decrease by some 35 percent, with a 50 percent reduction by 2015 (Fig. 1). Substantial loss of capability is likely over the next several years due to a combination of decreased budgets and aging satellites already well past their design lifetimes.

In its report, the committee sets forth a series of near-term and longer-term recommendations in order to address these troubling trends. It is important to note that this report does not "shoot for the Moon," and indeed the committee exercised considerable restraint in its recommendations, which were carefully considered within the context of challenging budget situations. Yet, while societal applications have grown ever-more dependent upon our Earth observing fleet, the NASA Earth science budget has declined some 30 percent in constant-year dollars since 2000 (Fig. 2). This disparity between growing societal needs and diminished resources must be corrected. This leads to the report's overarching recommendation:

The U.S. Government, working in concert with the private sector, academe, the public, and its international partners, should renew its investment in Earth observing systems and restore its leadership in Earth science and applications.

The report outlines near-term actions meant to stem the tide of capability deterioration and continue critical data records, as well as forward-looking recommendations to establish a balanced Earth observation program designed to directly address the most urgent societal challenges facing our nation and the world (see Fig. 3 for an example of how nine of our recommended missions support in a synergistic way one of the societal benefit areas—extreme event warnings). It is important to recognize that these two sets of recommendations are not an "either/or" set of priorities. *Both* near-term actions *and* longer-term commitments are required to stem the tide of capability deterioration, continue critical climate data records, *and* establish a balanced Earth observation program designed to directly address the most urgent societal challenges facing our nation and the world. It is important to "right the ship" for Earth science, and we simply *cannot* let the current challenges we face with NPOESS and other troubled programs stop progress on all other fronts. Implementation of the "stop-gap" recommendations concerning NPOESS, NPP, and GOES–R is important—and the recommendations for establishing a healthy program going forward are equally as important. Satisfying near-term recommendations without placing due emphasis on the forward-looking program is to ignore the largest fraction of work that has gone into this report. Moreover, such a strategy would result in a further loss of U.S. scientific and technical capacity, which could decrease the competitiveness of the United States internationally for years to come.

Key elements of the recommended program include:

1. Restoration of certain measurement capabilities to the NPP, NPOESS, and GOES–R spacecraft in order to ensure continuity of critical data sets.
2. Completion of the existing planned program that was used as a baseline assumption for this survey. This includes (but is not limited to) launch of GPM in or before 2012, securing a replacement to Landsat 7 data before 2012.
3. A prioritized set of 17 missions to be carried out by NOAA and NASA over the next decade (see Tables 1 and 2 below). This set of missions provides a sound foundation for Earth science and its associated societal benefits well beyond 2020. The committee believes strongly that these missions form a minimal, yet robust, observational component of an Earth information system that is capable of addressing a broad range of societal needs.
4. A technology development program at NASA with funding comparable to and in addition to its basic technology program to make sure the necessary technologies are ready when needed to support mission starts over the coming decade.
5. A new "Venture" class of low-cost research and application missions that can establish entirely new research avenues or demonstrate key application-oriented measurements, helping with the development of innovative ideas and technologies. Priority would be given to cost-effective, innovative missions rather than ones with excessive scientific and technological requirements.
6. A robust NASA Research and Analysis program, which is necessary to maximize scientific return on NASA investments in Earth science. Because the R&A programs are carried out largely through the Nation's research universities, such programs are also of great importance in supporting and training the next generation of Earth science researchers.
7. Sub-orbital and land-based measurements and socio-demographic studies in order to supplement and complement satellite data.
8. A comprehensive information system to meet the challenge of production, distribution, and stewardship of observational data and climate records. To

ensure the recommended observations will benefit society, the mission program must be accompanied by efforts to translate raw observational data into useful information through modeling, data assimilation, and research and analysis.

Further, the committee is particularly concerned with the lack of clear agency responsibility for sustained research programs and the transitioning of proof-of-concept measurements into sustained measurement systems. To address societal and research needs, both the quality and the continuity of the measurement record must be assured through the transition of short-term, exploratory capabilities, into sustained observing systems. The elimination of the requirements for climate research-related measurements on NPOESS is the most recent example of the failure to sustain critical measurements. Therefore, our committee recommends that the Office of Science and Technology Policy, in collaboration with the relevant agencies, and in consultation with the scientific community, should develop and implement a plan for achieving and sustaining global Earth observations. This plan should recognize the complexity of differing agency roles, responsibilities, and capabilities as well as the lessons from implementation of the Landsat, EOS, and NPOESS programs.

In your invitation, Mr. Chairman, you asked me to explicitly address a number of issues and I am pleased to do so:

1. What, in your perspective, should be the top three priorities for the NASA Earth sciences program over the next five years, and what, if any, are the most significant challenges in meeting those priorities?

This is a somewhat difficult question to answer. Five years from now is well into the period covered by the Decadal Survey, and the Survey has recommended a balanced set of 15 high priority missions for NASA. This set of 15 missions was derived from over 100 proposed missions, so a great deal of priority setting has already taken place by the community. It is therefore important to make progress on all of these missions during the next five years, with greater attention paid to the recommended missions early in the queue (the 2010 to 2013 timeframe as described in the report). Thus my answer to this question will focus on the highest priorities to begin in FY08 in order to lay the foundation for implementing the full set of recommendations during the next decade.

- First, NASA should commit to and begin to implement its recommended Decadal Missions. Although, the NASA budget for Earth Sciences is not now adequate to implement the survey recommendations (see next question), a useful start can be made with modest resources. The survey's initial seven missions (2010–2013) should begin in 2008; the first four (CLARREO, SMAP, ICESat-II, and DESDynI) should begin intensive Phase A activities and the next three (for the time period 2013–2016—HyspIRI, ASCENDS, and SWOT) should begin pre-Phase A studies. *Increment needed beyond President's Request in FY08: $90 million.*
- Second, NASA should increase its sub-orbital capabilities. NASA's airborne programs have suffered substantial diminution and should be restored. In addition, NASA should lead in exploiting unmanned aerial vehicles (UAV/technology). Both conventional and UAV aircraft are needed for instrument development, and hence risk reduction and technology advancement, and for their direct contribution to Earth observations. *Increment needed beyond President's Request in FY08: $10 million.*
- And third, NASA should increase support of its Research and Analysis (R&A) program and in Earth System modeling. Improved information about potential future changes in climate, weather, and other environmental conditions is essential for the benefit and protection of society. This improvement will come from: a) better observations (the recommended missions and enhanced sub-orbital capabilities); b) more capable models of the Earth System; and c) a vigorous research program to use the observations in models and interpret the results. The R&A program has suffered significant cuts in recent years and these should be reversed. R&A investments are among the most cost-effective as they directly exploit on-going missions, advance knowledge to better define what is needed in the future, and sustain and develop the requisite scientific and engineering workforce. *Increment needed beyond President's Request in FY08: $20 million.*

2. What are your perspectives on how well the FY 2008 budget request and out year projections for NASA's Earth science program align with the recommendations of the Earth science decadal survey?

The FY 2008 budget request for NASA's Earth science program is inadequate to meet the recommendations of the decadal survey. Figure 2 compares the request and the requirements to carry out the recommendations. Even with an encouraging increase in the NASA Earth Science request for FY08, it still falls short of what is needed to get a full start on the recommended program. Moreover, the out year projections show a *steady decrease* when the requirements call for an increase to a level of about $2.1 billion by 2010 with a level budget (in real dollars) after that.

This committee's leadership on Earth sciences and the recent actions in the House appropriations process with respect to FY08 are encouraging and greatly appreciated. I am hopeful that the Congress and the Administration will ultimately support the actions taken by this Committee and the appropriators in the FY08 appropriations process and continue to build on that momentum into the future.

3. Could you please describe your views on how NASA might begin to implement the recommendations of the National Academies' Earth science decadal survey?

It is a truism that to begin a long journey you have to take the first step. NASA should first commit to implementing the recommendations in a timely fashion, and then begin developing implementation plans and schedules for the recommended missions and supporting research and technology development. I am encouraged that NASA is planning workshops to further analyze the decadal survey recommended missions, but to develop the survey ideas further will require substantial investments.

Implementing the survey results will require modest increments in the NASA Earth Science budget, restoring the budget back to where it was in real dollars in the early part of this decade. This will require NASA to request the necessary resources and for Congress to provide them. Alternatively, Congress could take the lead and require NASA to implement the survey while providing the resources.

My recommended first specific steps for implementation are given in my answer to the first question.

4. What are your perspectives, as an individual researcher, on international collaborations in the Earth sciences, and what value would international collaborations offer in advancing the recommended missions in the decadal survey?

As the survey states, international partnerships can be very important in implementing complex expensive space missions such as recommended in the survey. Collaborations with other nations not only save scarce resources for all the partners, they promote scientific collaboration and sharing of ideas among talented people of all nations. Most of the smart people in the world do not live in the United States! International collaborations increase the brain pool to carry out the challenging proposed missions and use the observations in creative, innovative ways for the benefit of society.

However, international collaborations come at a cost. Any time partners are involved, control must be shared and the success of the mission depends critically on the performance of all the partners. If one partner runs into difficulties (e.g., financial support is withdrawn), the entire mission can be threatened. A successful collaboration also requires assurance that data will be shared and that U.S. scientists are full partners on teams that ensure adequate pre-launch instrument characterization and post-launch instrument calibration and validation. Other issues such as regulations governing the sharing of technologies (e.g., International Traffic in Arms Regulation—ITAR), governance and even language and cultural differences can make international partnerships more difficult and risky than "going it alone." Nevertheless, the potential benefits outweigh the downsides and NASA, NOAA and their U.S. partners in academia and industry should seek opportunities for international partnerships at every turn.

Mr. Chairman, the observing system we envision will help establish a firm and sustainable foundation for Earth science and associated societal benefits through the year 2020 and beyond. It can be achieved through effective management of technology advances and international partnerships, and broad use of satellite science data by the research and decision-making communities. Our report recommends a path forward that restores U.S. leadership in Earth science and applications and averts the potential collapse of the system of environmental satellites. As documented in our report, this can be accomplished in a fiscally responsible manner, and *I urge the Committee to see that it is accomplished.*

I close my testimony with a quote from Vice Admiral Richard H. Truly, former NASA Administrator, Shuttle Astronaut and the first commander of the Naval

Space Command in a recent report, *National Security and the Threat of Climate Change.* Admiral Truly speaks as one of 11 retired senior military officers who wrote this report that describes the serious threat of climate change to the Nation's security. Describing his experience in space 25 years ago, Admiral Truly said:

> *I have images burned in my mind that will never go away—images of the Earth and its fragility. I was a test pilot. I was an aviator. I was not an environmentalist. But I do love the natural environment, and seeing the Earth from space was the experience that I return to when I think about what we know now about climate. . .*
>
> *When you look at the Earth's horizon, you see an incredibly beautiful, but very thin line. That thin line is our atmosphere. And the real fragility of our atmosphere is that there's so little of it. . .*
>
> *The stresses that climate change will put on our national security will be different than any we've dealt with in the past. For one thing, unlike the challenges we are used to dealing with, these will come upon us extremely slowly, but come they will, and they will be grinding and inexorable. . .*

Admiral Truly said he was not convinced of the importance of climate change by any person or interest group—he was convinced by the data. We as a nation must continue to provide the data on the Earth, for only the data can reveal the truth that will affect us all.

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

Supporting Tables and Graphics

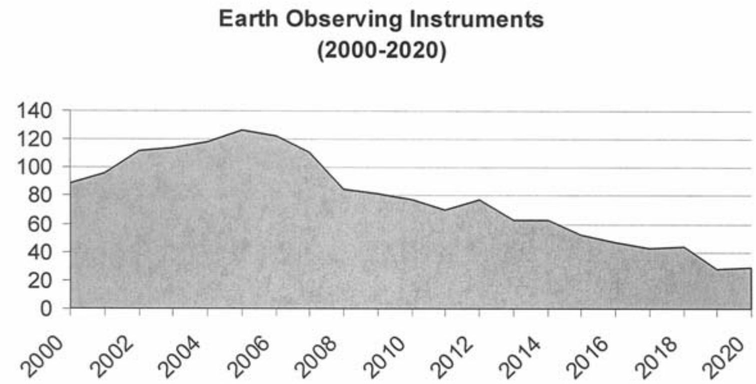


Fig. 1. Number of current and planned U.S. space-based Earth Observations instruments, not counting the recommended missions in the Committee's report. For the period from 2007 to 2010, missions were generally assumed to operate for four years past their nominal lifetimes. SOURCE: Information from NASA and NOAA websites for mission durations.

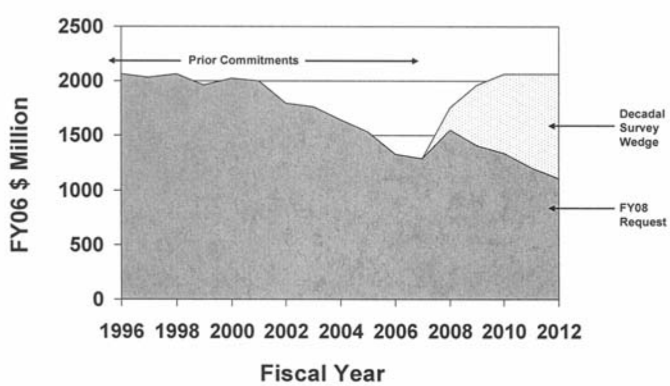


Fig. 2. NASA budget for Earth Sciences adjusted to constant FY 2006 dollars and adjusted for the effects of full-cost accounting. The required budget to implement the recommendations in the Decadal Survey Report would restore the Earth Sciences budget to the level at the early part of decade. SOURCE: President's Budget Request for 2008 and Decadal Survey Report.

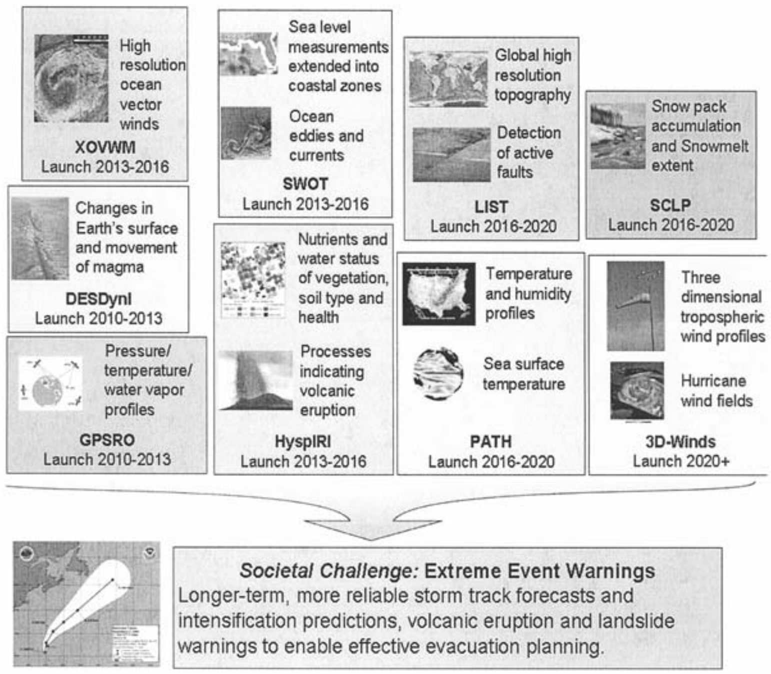


Fig. 3. Illustration showing how recommended missions work together to address societal challenges. Numerous additional examples are available in Chapter 2 of the final report.

TABLE 1. Launch, orbit, and instrument specifications for the recommended NOAA missions. Shade colors denote mission cost categories as estimated by the NRC committee. Green and blue shadings represent medium ($300 million to $600 million) and small (<$300 million) missions, respectively. Detailed descriptions of the missions are given in Part II of the final report, and Part III provides the foundation for selection.

Decadal Survey Mission	Mission Description	Orbit	Instruments	Rough Cost Estimate
Timeframe 2010 - 2013—Missions listed by cost				
CLARREO (Instrument Re-flight Components)	Solar and Earth radiation characteristics for understanding climate forcing	LEO, SSO	Broadband radiometers	$65 M
GPSRO	High accuracy, all-weather temperature, water vapor, and electron density profiles for weather, climate and space weather	LEO	GPS receiver	$150 M
Timeframe 2013 – 2016				
XOVWM	Sea surface wind vectors for weather and ocean ecosystems	LEO, SSO	Backscatter radar	$350 M

TABLE 2. Launch, orbit, and instrument specifications for the recommended NASA missions. Shade colors denote mission cost categories as estimated by the NRC ESAS committee. Pink, green, and blue shadings represent large ($600 million to $900), medium ($300 million to $600 million), and small (<$300 million) missions, respectively. Missions are listed in order of ascending cost within each launch timeframe. Detailed descriptions of the missions are given in Part II of the final report, and Part III provides the foundation for selection.

Decadal Survey Mission	Mission Description	Orbit	Instruments	Rough Cost Estimate
Timeframe 2010 – 2013, Missions listed by cost				
CLARREO (NASA portion)	Solar and Earth radiation, spectrally resolved forcing and response of the climate system	LEO, Precessing	Absolute, spectrally-resolved interferometer	$200 M
SMAP	Soil moisture and freeze/thaw for weather and water cycle processes	LEO, SSO	L-band radar L-band radiometer	$300 M
ICESat-II	Ice sheet height changes for climate change diagnosis	LEO, Non-SSO	Laser altimeter	$300 M
DESDynI	Surface and ice sheet deformation for understanding natural hazards and climate; vegetation structure for ecosystem health	LEO, SSO	L-band InSAR Laser altimeter	$700 M
Timeframe: 2013 – 2016, Missions listed by cost				
HyspIRI	Land surface composition for agriculture and mineral characterization; vegetation types for ecosystem health	LEO, SSO	Hyperspectral spectrometer	$300 M
ASCENDS	Day/night, all-latitude, all-season CO_2 column integrals for climate emissions	LEO, SSO	Multifrequency laser	$400 M
SWOT	Ocean, lake, and river water levels for ocean and inland water dynamics	LEO, SSO	Ka-band wide swath radar C-band radar	$450 M
GEO-CAPE	Atmospheric gas columns for air quality forecasts; ocean color for coastal ecosystem health and climate emissions	GEO	High and low spatial resolution hyperspectral imagers	$550 M

ACE	Aerosol and cloud profiles for climate and water cycle; ocean color for open ocean biogeochemistry	LEO, SSO	Backscatter lidar Multiangle polarimeter Doppler radar	$800 M
Timeframe: 2016 -2020, Missions listed by cost				
LIST	Land surface topography for landslide hazards and water runoff	LEO, SSO	Laser altimeter	$300 M
PATH	High frequency, all-weather temperature and humidity soundings for weather forecasting and SST[a]	GEO	MW array spectrometer	$450 M
GRACE-II	High temporal resolution gravity fields for tracking large-scale water movement	LEO, SSO	Microwave or laser ranging system	$450 M
SCLP	Snow accumulation for fresh water availability	LEO, SSO	Ku and X-band radars K and Ka-band radiometers	$500 M
GACM	Ozone and related gases for intercontinental air quality and stratospheric ozone layer prediction	LEO, SSO	UV spectrometer IR spectrometer Microwave limb sounder	$600 M
3D-Winds (Demo)	Tropospheric winds for weather forecasting and pollution transport	LEO, SSO	Doppler lidar	$650 M

[a] Cloud-independent, high temporal resolution, lower accuracy SST to complement, not replace, global operational high accuracy SST measurement.

BIOGRAPHY FOR RICHARD A. ANTHES

Richard Anthes is the President of the University Corporation for Atmospheric Research (UCAR). He is a highly regarded atmospheric scientist, author, educator and administrator who has contributed considerable research in the atmospheric sciences. Dr. Anthes has published over 100 peer-reviewed articles and books and participated on or chaired over 40 different U.S. national committees. He has also received numerous awards for his sustained contributions to the atmospheric sciences. In October 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 science and weather forecasting in China. Most recently, Dr. Anthes was named the President of the American Meteorological Society for 2007.

Dr. Anthes has made many research contributions in the areas of tropical cyclones and mesoscale meteorology. He developed the first successful three-dimensional model of the tropical cyclone and is the father of one of the world's most widely used mesoscale models, the Penn State-NCAR mesoscale model, now in its fifth generation (MM5). In recent years he has become interested in the radio occultation technique for sounding Earth's atmosphere and was a key player in the highly successful proof-of-concept GPS/MET satellite experiment and the present COSMIC (Constellation Observing System for Meteorology, Ionosphere and Climate satellite mission.

He places a very high value on education at all levels. His philosophy is that any significant, long-term progress in solving the array of problems facing the world hinges on the education of young people in all countries. This philosophy is reflected in multiple education and outreach programs at UCAR. For example, in 1996 he initiated the highly successful SOARS (Significant Opportunities in Atmospheric Research and Science) program, which addresses the severe under-representation of minority professionals in the atmospheric sciences. This program received the Presidential Mentoring Award for Excellence in Science, Mathematics and Engineering in 2001.

Chairman UDALL. Thank you, Dr. Anthes.

Dr. Barron.

STATEMENT OF DR. ERIC J. BARRON, DEAN, JACKSON SCHOOL OF GEOSCIENCES; JACKSON CHAIR IN EARTH SYSTEM SCIENCE, UNIVERSITY OF TEXAS, AUSTIN

Dr. BARRON. Mr. Chairman, Members of the Subcommittee, thank you for allowing me to testify today.

I believe we have one key goal and that is to simultaneously protect life and property, promote economic vitality and at the same time enable environmental stewardship. Achieving that balance is quite a challenge, and at a minimum, to be successful, we have to do two things. We have to know what components of the Earth system are changing and how they are changing and an ability to separate out the human activity from the natural forces, and we need to be able to do a better job of anticipating or predicting the future. It is our ability to anticipate the future that makes knowledge about the Earth so powerful.

Our scientific community is very appreciative of the actions taken by Congress at the start of the fiscal year 2008 appropriations process as you and your colleagues make real efforts to strengthen the NASA Earth Sciences program. Unfortunately, the 2008 budget request and its out-year projections are just not adequate. Under that current funding and projections, the United States will have significant gaps in long-term observations, making it much more difficult to separate out natural and human contributions to climate change and making it much more difficult to assess how the Earth is changing. It is equivalent to knowing that we are having an intense debate for policy-makers on the importance of solar versus greenhouse gases and so now let us break this record so that it becomes even more challenging, to answer that question. Under current funding and projections, the key areas of uncertainty in climate models, this ability to anticipate the future so we can put knowledge to good use will likely continue to languish.

I would also like to stress the fact that the Decadal Survey seeks primarily to ensure a reasonable and robust set of observations within a tractable budget where tractable is defined as only restoring the budget to its 2001 level in terms of real dollars while ensuring that the most critical observations and certainly not all that are needed are addressed. For climate studies, the list provided in the Decadal Survey is truly a base set. Each element is critical and the list is not sufficient to address all the major uncertainties in forecasting the future. First, the Decadal Survey seeks to sustain the multi-decadal global measurements of key climate variabilities in order to understand how the Earth is changing, to understand the roles of natural versus human portion and to assess and improve climate models. The list is really a list of fundamentals. The input of energy from the sun, the Earth's energy budget, the atmosphere temperature and water vapor, sea surface temperatures, sea surface height, the distribution of snow and ice, ozone profiles, aerosols and surface winds is truly a basic set of variables to try to describe how our climate system is changing.

Second, the Decadal Survey seeks to tackle a key issue, the mass balance and stability of the large icecaps. The Decadal Survey places a high priority on determining the ice sheet volume, sea ice thickness, ice sheet surface velocities and improved estimates of the sensitivity of ice sheets to change. This is an area of great sensitivity in the climate system and a huge question we have in front of us is how stable are those ice sheets.

Third, the Decadal Survey calls for a focus on the two areas that are considered to be the most limiting in terms of our ability to improve climate model predictions. The first area is aerosol cloud forcing. It is one of the great remaining uncertainties in climate models. The second area addresses key uncertainties in the ocean circulation, ocean heat, storage and uptake and ocean climate forcing.

If we fail to implement the Decadal Survey recommendations, we will have an observing system and a NASA research program that is much less capable than the one we had at the start of this century. The impact on our knowledge base could also be profound. It may be a much longer-term impact than we realize. It is interesting to note that these climate issues are becoming increasingly important to the public, and I believe that the demand for information from the public will begin to grow. This is occurring at a time where we have considerable weakness in the observation program and the research and analysis program and it is occurring at the same time in which much of the NASA workforce is eligible to retire, and if you don't have those opportunities, you are not going to entrain the next generation workforce and so have the potential to be doing very long-term damage to the Earth sciences by having this delay.

Thank you for your time, and I welcome any questions.

[The prepared statement of Dr. Barron follows:]

PREPARED STATEMENT OF ERIC J. BARRON

Mr. Chairman, Ranking Minority Member Calvert, and Members of the Subcommittee: I appreciate the opportunity to provide this testimony on *NASA's Earth Science and Applications Programs: Fiscal Year 2008 Budget Request and Issues.* My name is Eric Barron, and I am Dean of the Jackson School of Geosciences at the University of Texas at Austin. I was also the Chair of the Climate Variability and Change Panel, which was one of the key components of the National Research Council (NRC)'s Committee on Earth Science and Applications from Space: A Community Assessment and Strategy for the Future.

Our most basic objective is to simultaneously protect life and property, promote economic vitality, and enable environmental stewardship. Regardless of our views on climate change, we all recognize that this objective is a balancing act. It is impossible to have billions of people on a planet and not have an environmental impact. Impact is also clearly associated with individual, regional and national levels of consumption. We also know that nations that have the strongest economies are the ones who are the most capable of adapting to change or mitigating its adverse consequences. Finding the optimum balance is enormously challenging and is in itself a subject of great debate. However, it becomes impossible if we lack sufficient knowledge of how the Earth operates. We need a commitment in two key areas if we are to achieve this most basic objective. First, we need to know how the components of the Earth are changing in response to human activity and natural forces. Second, we need to continue to improve our ability to "anticipate" or predict the future on a variety of time scales. If current climate projections are correct, climate change over the next ten to twenty years will have highly noticeable impacts on society and the demand on climate scientists will begin to broaden substantially. Impacts on agriculture, water resources, human health, and ecosystems are likely to drive a public demand for climate knowledge that is both sector (agriculture, health, water, etc.) and regionally dependent. It will be our ability to anticipate or forecast all of these elements in the future, and then to take appropriate action on these predictions with full understanding of their uncertainties, that can enable us to simultaneously protect life and property, promote economic vitality, enable environmental stewardship, and help assess a broad range of policy options for decisionmakers.

This view yields six key tenets that should define the observation systems of the future:

(1) Sustained multi-decadal, global measurements and data management of quantities that are key to understanding the state of the climate and the changes taking place are crucial.

(2) Climate change research, including the observational system, will be increasingly tied directly toward understanding the processes and interactions needed to improve our predictive capabilities and resolve the probabilities associated with different outcomes.

(3) Evaluation and assessment of model capability will increasingly be the focus of future measurement activities. Demonstrating model capability is likely to be a driver for developing and evolving observation systems and field campaigns.

(4) The link between climate research and societal benefit will require a much greater emphasis on higher spatial resolutions in climate predictions, observations, and assessments.

(5) The "family" of climate observing and forecasting products will continue to grow, involving innovative research into societal connections with energy, agriculture, water, human health, and a host of other areas, creating new public and private partnerships.

(6) The demand to understand the connection between climate and specific impacts on natural and human systems will require a more comprehensive approach to environmental observation and modeling in order to integrate the multiple stresses that influence human and natural systems (i.e., climate, land use, and other human stressors such as pollutants).

The importance of climate information is clear. As economic impact from climate change grows there will likely be both a change in research emphasis and a demand for much greater investment in climate research. Yet, the NASA investment in climate research and observation is in serious decline. We will enter the next decade with an observing system that is substantially less capable than we had at the start of the 21st century.

The specific questions provided by the Subcommittee help elucidate this issue and I am pleased to answer them to the best of my ability.

(1) What is NASA's contribution to the U.S. Climate Science Research Program in terms of percentage of overall expenditures and percentage of sensors dedicated to studying Earth's Climate? What fraction of the world's effort on climate change research does NASA's contribution represent?

At the start of the U.S. Global Change Research Program, considerable effort was invested in labeling the contributions of each federal agency to the components of global change research including climate. Further, this analysis identified contributions to the observing and modeling components of the investment in climate research. In 1992, NASA contributions were approximately 70 percent of the total USGCRP budget, with more than a third of the total USGCRP budget focused on climate and hydrology observations provided by NASA (about $400 million of a total budget of $1,185 million). A decade later, growth in NASA investments in USGCRP kept pace with the growth in the total budget, and also kept pace in terms of the investment in climate research. In the FY08 request, NASA's investment is about 60 percent of the total Climate Change Science Program (CCSP) and the total CCSP budget request is about 6.5 percent above the 2002 USGCRP budget (figures not adjusted for inflation). The full set of segmented disciplinary topics within the USGCRP set of cross-cuts is combined into one CCSP budget. More telling is an analysis of the out-year budgets with their associated numbers of missions and instruments. Even with the extension of some current missions beyond their nominal life times, by 2010 the U.S. will have a 35 percent decrease in the number of operating sensors and instruments on NASA spacecraft. By 2015, the number will have decreased by more than 50 percent. In real dollars, NASA Earth Sciences has declined by more than a half a billion dollars since the 2002 USGCRP budget.

The total international investment in climate science is difficult to confirm with certainty by the science community, but NASA has always been the international leader in Earth observations. The decrease in research, missions, and numbers of instruments is a real loss of capability. The baton is not being passed to international partners, it is simply being dropped.

(2) What are your perspectives on the FY 2008 budget request for NASA's Earth Science Program and how well does it position NASA to contribute to the U.S. priorities and plans for climate and related research?

The modest increase in the FY 2008 budget request for NASA's Earth Science Program is the first sign that the steady erosion of capability and the lack of a credible program of observations beyond the end of this decade is reversing. However, the FY 2008 budget and its out-year projections are simply inadequate. Under current funding and projections, the U.S. will have significant gaps in the long-term observation record, making it more difficult to separate natural and human contributions to climate change and making it more difficult to assess how the Earth is changing. Debates on issues such as the relative importance of solar versus greenhouse causes of warming will continue rather than be solved definitively. Under current funding and projections, the key areas of uncertainty in climate models will very likely continue to languish. Most certainly, the areas of investigation that couple climate change to societally-important areas such as water, health, and food security will be delayed. Stated frankly, our capabilities to address critical questions in climate change in service to society will experience a dramatic decline if the NASA out-year projections are realized.

(3) Which missions and observations recommended in the National Academies Earth science decadal survey are most critical for advancing our understanding of climate change and any mitigation and adaptation strategies? What uncertainties in our understanding of change would the observations from those missions help reduce?

In my opinion, a decadal survey in the Earth sciences produced a decade ago would have focused on innovation built upon a robust global observing system. Such a survey would likely have focused on new technologies and new capabilities that would have extended our abilities to address difficult variables, improve the quality of our observations, and demonstrate an increase in forecasting capability. Certainly, we would have debated how to balance the notion of entraining new technologies while still preserving continuity of the observations. Likely, we would have debated the best mechanisms to bring the same "discipline of forecasting" that has resulted in dramatic improvements in weather forecasting to a much broader family of variables of interest to our society. In contrast, the Decadal Survey rarely considered the frontiers that we know are in the realm of the possible. This is not a critique of the Decadal Survey. It is a fact that the NRC effort sought primarily to ensure a reasonable and robust set of observations within a tractable budget, where "tractable" is defined as only restoring the budget to its level in 2001 in terms of real dollars, while ensuring that the most critical needs were addressed.

For climate studies, the list provided in the National Academies Earth Science Decadal Survey is a base set. It is prioritized in time, taking into account the existing instrumentation and international partners, but each element is critical and the list is not sufficient to solve all of the major uncertainties in forecasting the future. It maintains the most basic needs and adds only those missions which are clearly the most crucial priorities in a set of many critical observations. The request for climate research reveals the level of constraint applied within the Decadal Survey.

First, we must have a sufficient set of sustained multi-decadal, global measurements of key variables in order to understand how the Earth is changing, to understand the roles of various natural and human forcing factors, and to assess climate models. Stripped to its fundamentals, the climate is first affected by the long-term balance between incoming and outgoing energy. Both the long-term records of total solar input and the Earth's energy budget are in jeopardy. Other variables that define the state of the atmosphere and ocean and provide a foundation for both weather forecasting and climate are equally critical. These include such fundamental observations as temperature and water vapor soundings, the distribution of snow and ice, ozone profiles, and surface winds. The de-scoping of NPOESS involved each of these key climate variables. Without the Decadal Survey recommendations we do not address these most basic needs of the climate sciences.

Second, current observations and models raise particular concerns about the mass balance and even the stability of the large ice caps. In terms of our capabilities to assess how the Earth system is changing, the ice sheets represent one of the most significant areas of uncertainty and one of the most significant areas in terms of potential societal impact. The Decadal Survey places a high priority on determining ice sheet volume, sea ice thickness, ice sheet surface velocities, and improved estimates of the sensitivity of the ice sheets to climate change.

Third, the Decadal Survey calls for a focus on the two areas that are considered to be the most limiting in terms of our ability to improve climate model predictions. The first area is aerosol-cloud forcing. Aerosol climate forcing is similar in magnitude to carbon dioxide forcing, but the uncertainty is estimated to be substantially larger. The impact of aerosols on cloud formation amplifies their importance to the climate system. The Decadal Survey also calls for a focus on measuring ocean circulation, ocean heat storage and ocean climate forcing. Again, the problems are fundamental, involving the measurement of sea level, the importance of how rapidly heat is being mixed into the oceans, and improvements in our ability to simulate the ocean circulation.

We are more than capable of providing the observations needed to address the specific topics above. Importantly, the climate chapter of the Decadal Survey also calls for us to address much more challenging problems by bringing innovative approaches to the fore and challenging our ability to return to the cutting-edge of Earth observing. The accurate measurement of the surface fluxes of energy, water and momentum at the Earth's surface, and an improved ability to examine atmospheric convection (which governs the transport of heat, water vapor, trace gases, and aerosols and defines cloud formation) would substantially advance our ability to predict the future and to understand critical problems such as sea level variations and changes in the distribution and character of precipitation. Missions dedicated to these two important topics are not a part of the priority set from the Decadal Survey.

(4) What role, if any, do NASA's Earth science research and related programs play in validating the accuracy of climate measurements collected from Earth observing satellites and in developing predictive capabilities for climate change and its effects?

The decline in capability is not restricted to missions and instruments. The decline in the observation budget is matched by a significant decline in the Research and Analysis budget in the Earth Sciences. Sub-orbital and land-based studies increase our ability to assess and validate climate measurements. A comprehensive approach to the analysis, distribution and stewardship of observations broadens the base of applications and entrains a broader set of disciplines and a higher level of expertise directed toward increasing our confidence in Earth observations, expanding their value, and improving predictive capabilities.

The loss of capability has the potential to be long-term and particularly costly because of its timing. The lack of missions, the reduced level of opportunities, the lack of innovation, and the weakness in the Research and Analysis budgets are likely to result in a reduction in student interest, and most clearly in the training of graduate students and post-doctoral researchers. This loss of opportunity, with it potential impact on attracting the next generation of scientists and engineers who design sensor systems and analyze data, matches a time in which a substantial fraction of the NASA Earth sciences workforce is able to retire. The FY 2008 and out-year budgets have the potential to create significant weakness in the capability of the workforce at the same time that society is demanding an increased emphasis on understanding climate and its impacts.

(5) What are your perspectives, as an individual researcher, on international collaborations in the Earth sciences, and what value would international collaborations offer in advancing the recommended missions in the decadal survey?

In my opinion, the statements on international collaboration provided in the Decadal Survey are sound. International collaborations have a number of benefits including a reduction in cost and a potential reduction in the likelihood of gaps in key data sets. In addition, collaboration can increase the number of science users and bring a broader array of technologies to bear on a specific problem. NASA has demonstrated success in developing such partnerships, with TOPEX/Poseidon and RADARSAT–1 as good examples. Moreover, it is now relatively common for flight agencies to offer announcements of opportunity to the international science community as the agencies attempt to maximize the payoff of each flight project.

However, joint ventures must still be considered with care, particularly for climate data sets. As noted in the Decadal Survey climate chapter, instruments built by one partner may not be designed to the exact requirements of another partner. Although two missions may utilize the same type of instrument—for example an altimeter—and therefore sound like they are duplicative, the differences in design may allow one to resolve ocean eddies and improve our knowledge of the ocean circulation while the other may not achieve this objective. Technology transfer restrictions may also prevent the exchange of important technical details about the instruments. Restrictions on access to data and software vary from country to country, as do approaches to calibration and validation. Joint ventures between government flight agencies and commercial partners can result in serious complications with data cost, availability, and distribution. Missions can also be terminated or significantly altered by host countries, resulting in a greater impact if the other partners had counted on the international partner to provide a key observation or synergistic measurement.

International partnerships should only be fostered where synergy between instrument capabilities and the science requirements is strong, where there is free and easy access to data, and where there is transparency in the process of analyzing data such that analysis algorithms are freely available.

The Decadal Survey includes many examples where priorities were altered based on knowledge of missions proposed by international partners. A case in point is the cloud-aerosol mission (ACE) proposed by the Decadal Survey which, despite its importance in addressing areas of uncertainty in climate models, was placed in phase 2 (2013–2016) because of cloud and aerosol information that would become available from international sources (GCOM–C and EarthCARE).

End Note

An improved ability to predict climate change will allow us to be good stewards of this planet. But few seem to recognize that our ability to better predict the future has benefit far beyond addressing the consequences of increased levels of greenhouse gases. The potential societal benefits are substantial. For example, even modest improvement in seasonal to interannual predictions have the potential for significant societal benefit in agriculture, energy, water, and weather-related management. The Decadal Survey presents a vision that recognizes that the demand for knowledge of climate change and variability will increase. The risk in failing to provide this information is high. However, our ability to serve society through increased observing capability and improved model prediction is far greater than a single issue, even though the issue of climate change is of enormous significance. An improvement in our ability to anticipate the future increases our capability to utilize this knowledge to both limit adverse outcomes and maximize benefits to society.

BIOGRAPHY FOR ERIC J. BARRON

Date and Place of Birth:

26 October 1951, Lafayette, Indiana

Education:

1B.S., 1973, Florida State University (Geology)

M.S., 1976, University of Miami (Oceanography, Marine Geology and Geophysics)

Ph.D., 1980, University of Miami (Oceanography, Marine Geology and Geophysics)

Positions:

1980—Postdoctoral Research Fellow, National Center for Atmospheric Research, Boulder, Colorado

1981–1985—Scientist, Climate Section, National Center for Atmospheric Research, Boulder, Colorado

1985–1986—Associate Professor, University of Miami

1986– —Director, Earth System Science Center and Associate Professor of Geosciences, the Pennsylvania State University

1989– —Professor of Geosciences, the Pennsylvania State University

1998–2003—Director, EMS Environment Institute

2002– —Dean, College of Earth and Mineral Sciences

2002– —Trustee, University Corporation for Atmospheric Research (currently Vice Chair)

2003– —Board of Governors, Joint Oceanographic Institutions, Inc. (currently Vice Chair)

2006– —Dean, Jackson School of Geosciences

Professional Societies:

Fellow, American Geophysical Union

Fellow, American Meteorological Society
Member, Geological Society of America
Fellow, American Association for the Advancement of Science
Member, American Association of Petroleum Geologists
Member, Phi Kappa Phi

Honors:

1969–1973—Honors Student, Florida State University
1975–1977—Texaco Fellow
1976—National Center for Atmospheric Research Supercomputing Fellow
1977–1978—Outstanding Student Award, Miami Geological Society
1979–1980—Koczy Fellowship (most outstanding student in last year of study)
1980—Smith Prize (most creative dissertation)
1988—Excellence of Presentation Award, Society of Economic Paleontologists and Mineralogists
1989—Honorable Mention for Excellence of Presentation Award, Society of Economic Paleontologists and Mineralogists
1992—Wilson Research Award, College of Earth and Mineral Sciences, The Pennsylvania State University
1992, 1993—Provost Award for Collaborative Instruction and Curricular Innovations
1993—Excellence of Presentation Award, Society of Sedimentary Geology (SEPM)
1993—American Geophysical Union Fellow
1993—Honorable Mention for Excellence of Presentation (Poster), American Association of Petroleum Geologists
1995—American Meteorological Society Fellow
1997—American Association of Petroleum Geologist's Distinguished Lecturer
1999—Wilson Teaching Award, College of Earth and Mineral Sciences, the Pennsylvania State University
1999—NASA Outstanding Earth Science Education Product ("Discover Earth: Earth-as-a-System")
1999—Distinguished Professor of Geosciences
2001—NASA Group Achievement Award for "Research Strategy for the Earth Science Enterprise"
2002– —Fellow, the National Institute for Environmental eScience, Cambridge University, United Kingdom
2002—Frontiers in Geophysics Lecture, American Geophysical Union
2003—NASA Distinguished Public Service Medal
2004—American Association for the Advancement of Science Fellow

Related Experience:

Publications

1982–1989—Member, Editorial Board, *Geology*
1984–1985—Member, Editorial Board, *Palaeogeography, Palaeoclimatology, Palaeoecology*
1985–1991—Editor-in-Chief, *Palaeogeography, Palaeoclimatology, Palaeoecology*
1988–1996—Editor, *Global and Planetary Change*
1989–1995—Associate Editor, *Journal of Climate*
1991—Member, American Geophysical Union, Selection Committee *Paleoceanography* Editor
1992– —Member, Editorial Board, *Palaeogeography, Palaeoclimatology, Palaeoecology*
1994–1996—Member, Editorial Board, *Geotimes*
1994–2000—Member, Editorial Board, *Consequences*
1995, 1997—Chair, American Geophysical Union, Selection Committee, *Biogeochemical Cycles* Editor
1995–1999—Editor-in-Chief, *Earth Interactions* (electronic journal of AMS, AGU and AAG)

1998—Editorial Board, Oxford University Press, *Global Change Encyclopedia*

Service to Societies

1986–1990—Member, American Meteorological Society Committee on Climate Variations

1988–1991—Chair, American Meteorological Society Committee on Climate Variations

1988–1990—Member, Global Sedimentary Geology Program Committee, Society of Economic Paleontologists and Mineralogists

1991—Chair, Penrose Conference Committee, Geological Society of America

1990–1991—Member, American Geophysical Union, Maurice Ewing Medal Subcommittee

1991–1996—Chair, American Meteorological Society Annual Meeting Program Committee for Global Change

1994—Member, American Geophysical Union, Small Science Panel

1995–2002—Member, American Geophysical Union Atmospheric Sciences Executive Committee

1998—Citation Author-American Geophysical Union, Revelle Medal

1998–   —Member, American Geophysical Union, Horton Award Subcommittee

2003—Member, American Meteorological Society, Mid-term Strategic Planning Assessment team

2005—Chair, American Geophysical Union, NASA Vision Panel

National Research Council

1987–1990—Member, Climate Research Committee

1990–1996—Chair, Climate Research Committee

1989—Member, Study Committee on Earth System History and Modeling, Global Change Committee

1990–1994—Member, Board on Global Change Research

1992–1996—Member, Committee on Human Dimensions of Global Change

1995–1997—Member, Board on Atmospheric Sciences and Climate

1997–1999—Co-Chair, Board on Atmospheric Sciences and Climate

1999–2003—Chair, Board on Atmospheric Sciences and Climate

1997–2002—Ex-officio, Committee on Global Change Research

1998–2000—Member, Panel on Grand Environmental Challenges

1999—Member, Panel on Assessment of NASA Post-2000 Plans

2002–2003—Member, Panel on Tracking and Predicting the Atmospheric Dispersion of Material Releases: Implications for Homeland Security

2003–2004—Chair, Committee on Metrics for Global Change Research

2004–2006—Member, Survey Steering Committee for Earth Science and Applications from Space: A Community Assessment and Strategy for the Future; Chair, Panel on Climate Change and Variability

2006–   —Member, Committee on Analysis of Global Change Assessments

Service to the Federal Government

1988—Member, NSF Review Panel, Ocean Drilling Program Plan, FY 1988–1990

1988–1990—Member, Ocean History Panel, NSF Ocean Drilling Program

1990–1994—Member, Science Executive Committee, NASA Earth Observing System

1994–1997—Chair, Science Executive Committee, NASA Earth Observing System

1990–1994—Chair, Climate and Hydrology Panel, NASA Earth Observing System

1990–1993—National Center for Atmospheric Research Scientific Computing Division Advisory Committee

1990–1993—Chair, NSF Advisory Committee, Marine Aspects of Earth System History (MESH)

1989–1993—Climate Systems Modeling Project Advisory Board

1991–1993—Member, NSF Review Panel for Geological Record of Global Change

1992–1993—Member, Earth Science and Applications Advisory Committee, NASA

1993—Chair, Earth Science and Applications Advisory Committee, NASA

1994–1997—Member, Earth Science and Applications Advisory Committee, NASA

1994–1995—National Center for Atmospheric Research Director's Advisory Committee

1994—Chair, USGCRP Forum on Global Change Modeling

1994–1996—Chair, U.S. National Committee for PAGES and NSF Earth System History Panel

1995–1996—Chair, Allocation Panel for Interagency Climate Simulation Laboratory

1995—Testimony, U.S. House of Representatives, Committee on Science, NASA Budget

1997—Testimony, U.S. Senate, Committee on the Environment and Public Works—Global Warming

1997–1999—Member, NSF Geosciences Advisory Committee

1997—Chair, NSF Committee of Visitors on Ocean Sciences Facilities

1997—Co-Chair, White House/USGCRP workshop on "Impact on Climate Variation in the Mid Atlantic States"

1997–2000—Member, USGCRP National Assessment of Climate Impacts Synthesis Team

1998–2000—Member, NSF Geosciences Strategic Planning Committee GEO–2000

1998– —Member, NOAA Panel on Long Term Climate Monitoring

1999– —Member, NASA Goddard Space Flight Center, Director's Advisory Committee

2000– —Member, DOE BERAC Subcommittee on Global Change

2000—Chair, Screening Committee, Director of Earth Sciences, Goddard Space Flight Center

2000—Member, EPA Review Panel, Integrated Assessment

2000—Member, DOE Review Panel, Climate Change Prediction

2001—U.S. Senate Testimony on Climate Change Science—Committee on the Environment and Public Works

2001—Testimony, U.S. House of Representatives, Committee on Science—NOAA Budget

2001—Briefing, U.S. House of Representatives, Committee on Science—Climate Change Science

2003– —Member, NSF Steering Committee for Cyberinfrastructure Research and Development in the Atmospheric Sciences

2003–2005—Member, Earth Science and Applications Advisory Committee, NASA

2005—Chair, NASA Senior Review for the Earth Sciences

2006—Chair, NSF Earth System History Review panel

International Service

1982–1987—Chair, International Geological Correlation Program (IGCP), Project 191, "Cretaceous Paleoclimatic Atlas Project"

1982–1986—Member, International Lithosphere Program (ILP), Working Group 7 "Paleoenvironmental Evolution of the Oceans and the Atmosphere"; Participant, Conference on Scientific Ocean Drilling (COSOD) Organizer, Penrose Conference on Cretaceous Climates

1982–1986—Member, SCOR Working Group 79, "Geological Variations in Carbon Dioxide and the Carbon Cycle"

1986–1987—Member, Global Environmental Change Panel for Conference on Scientific Ocean Drilling (COSOD II)

1988–1990—Organizer, Global Sedimentary Geology Working Group on Paleogeography and Paleoclimatology

1995—International Review Member, Ocean Drilling Program

1996–1997—Member, Joint Steering Committee, World Climate Research Program

Other

1980—Shipboard Scientist, RV Glomar Challenger Leg 75

1998—Chief Scientist, RV Oceanus

1998–2002—Elected, two terms, State College Area School Director

Chairman UDALL. Thank you very much, Dr. Barron.
Dr. Foresman.

STATEMENT OF DR. TIMOTHY W. FORESMAN, PRESIDENT, INTERNATIONAL CENTER FOR REMOTE SENSING EDUCATION

Dr. FORESMAN. Thank you, Mr. Chairman, Ranking Member and Members of the Subcommittee.

I would like to focus this committee's attention on applications to what I feel is the foremost critical arena for carrying forth the NASA Earth Science Application program mission for translation and engagement with the greater user community in our society. I am specifically referring to a 1999 initiative that existed among 17 federal agencies called Digital Earth, which was led by NASA Earth Sciences. These agencies formed a common objective to apply Web-based visualization technologies to enable data exchange among the various government departments.

Inter-operability of our government's information resources is a requisite step to addressing major decision support challenges facing our nation at local and state levels across a litany of compelling issues ranging from disaster warning and response to climate change research. NASA was leading 17 federal agencies in 1999 to create virtual three-dimensional Digital Earth geobrowsers, today's Google Earth. NASA was also leading the design of the underlying architecture to operate interconnecting systems with Earth observation science data and application. The potential promise of these technologies to display and share data and information was not lost upon our federal colleagues. They fully recognized that these astonishing Digital Earth capabilities would enable scientists and managers within our government to take full command of their own agency's information and resources and interlink with all other information available throughout the Federal Government.

Our industry and academic colleagues were quick to join with this engaging and visually enabled captivating initiative for Web-based collaboration, and indeed, many have continued to pursue this Digital Earth vision long after NASA began to decommission the interagency working group. This decommissioning was unfortunate, in my opinion. The loss of NASA's leadership, guidance and momentum for the Digital Earth initiative has proven to be a tremendous setback for critical areas in the Earth observation science program. The fact that geobrowsers such as Google Earth and Microsoft's Virtual Earth and many others can be directly linked to the Digital Earth legacy is testimony to the paramount importance of these technologies for their capacity to deliver science and information directly to the user community, and this is only the tip of the iceberg. Seven years later, NASA cannot deliver a decisive decision support system or a citizen alert system with anything resembling the ease of use and sophistication of Google Earth.

While working for the United Nations environment program, I launched Google Earth's first contract in 2001 when they were known as Keyhole. Where was NASA leading us in 2001? What is NASA's Earth Science Application program doing today to build real-world partnerships that can quickly create visualization solutions for complex problems? What is NASA doing to fully engage with these geobrowser technology teams to rapidly move forth on delivering Earth observation science and information to citizens and decision-makers? Market forces and free enterprise should not be allowed to replace NASA and its mission during our current era of global change and climate variability.

This is why I am most concerned that NASA's Earth Science Application program seriously rethinks its current trajectory and seriously engages with the creative forces of market and academia and NGOs but most important, NASA should seriously accept and assume the leadership role that it once held in this most fecund and catalytic domain of science and technology and apply this for the service of America and the world's citizens. When NASA declined to lead the Digital Earth initiative, the Chinese were happy to leap to the forefront during the last seven years and launched a series of international symposia and international journals and the International Society for Digital Earth.

An incredible range of phenomenal and societal shifting applications are currently underway applying Digital Earth including monitoring of Darfur human rights violations and conflicts, citizens' engagement with mountaintop removal issues in Appalachia, Yukon indigenous tribes assuming governance along the Yukon River Valley, grassroots women's groups creating peace maps for their community, and disaster response in Indonesia and Katrina. A small team at NASA Ames has developed a world-class and free open source Digital Earth geobrowser called World Wind. The World Wind team, about the same size as Google Earth's staff was back in 2001, has been struggling for funding and needs support. Private discussions ongoing between Google executives and Director Griffin regarding strategic goals and objectives of the Google-NASA Enterprise partnership should immediately be reviewed and considered by your Committee.

Rapid and collective action will be required to align NASA's Earth Science Application program with the pace of development and action occurring in today's technology, science and social landscape. Google Earth is just two years old. My team helped form and influence that trajectory with success six years ago. What can we expect of NASA over this next year?

Thank you, Mr. Chairman, Ranking Members and Members of the Committee.

[The prepared statement of Dr. Foresman follows:]

PREPARED STATEMENT OF TIMOTHY W. FORESMAN

1. How can NASA's Earth Science Applications Program enable the applied use of NASA Earth observation data for societal benefit?

NASA has a unique and valuable brand that facilitates connecting segments of society, nationally and internationally, with the benefits of Earth observation. This brand of credibility still retains a sense of intellectual awe that breaks through many barriers that other agencies or firms must overcome to convey similar communications and engagement. Therefore the first challenge for enablement comes with the brand.

Societal use is a broad term, well articulated in the National Research Council's 2007 report, *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond.* This witness is in full accord with the recommendations of the reference report and its recommendations, and will therefore attempt to elucidate for highlight specific items, elements, or recommendations that are not clearly defined in the report.

Society is facing an onslaught of changes that may responsibly be labeled of "biblical proportions." These actions are occurring at such a pace and scale, that science teams are challenged to locate their research plots and areas intact from one year to the next. Many forests have disappeared, for example, while science teams were debating the carbon budget and biomass contained within them. These societal onslaughts include:

- Atmospheric build up of greenhouse gases higher than experienced from 600,000 to one million years. Carbon dioxide in the atmosphere has passed the tipping point of 350 parts per million.[1]
- Humans are witnessing the sixth massive planetary epoch of species extinction recorded for the Earth.
- Approximately one billion people do not have access to safe drinking water.
- The 2002 Global Environmental Report (GEO 3) of the United Nations Environment Programme was not able to document one positive trend in desertification, deforestation, over fishing, arable land productivity, coral reef health, biodiversity, protection of migratory species, human security, disease vectors, or environmental sustainable practices.
- Climate change appears to be gaining momentum while coping strategies for the most vulnerable society members have not been put into place or are unknown.

NASA's Earth Science Applications Program (ESAP) has the potential to provide profound amounts of useful data and information across the litany of sectors that divide the human community operations. Forestry, fisheries, farming, education, health care, disaster response, community development, and governance all fulfill separate and compartmentalized domains of local and regional operations. NASA ESAP has developed a reasonably literate understanding of how information can flow from sensor collection to decision-making in the field. However, they lack the financial resources, the personnel with experience and expertise, and the requisite infrastructure to implement the process control and operations. They are limited by NASA's mandate for research, which is consistently used to set limits on the success of programs within NASA ESAP. **Therefore, major shifts in the follow arenas are recommend to be placed on the table if NASA ESAP plans to "enable the applied use of NASA Earth observation data of societal benefit."**

- Define the research continuum for NASA ESAP in harmony with the Department of Defense categories (e.g., 6.1 to 6.6 defines six levels of research and development, while NASA has no differentiation).
- Create multi-agency working groups with concrete deliverable for products, selectively rotating chair positions on an annual basis, and create funding mechanisms for shared contracting (e.g., with membership in the State Department's Humanitarian Information Unit).
- Break all grants and awards 50–50 percent into two sectors: (1) major institutions, and (2) small business and NGOs. Currently the vast major of funds go to Congressional earmarks or distributed to larger organizations and universities with a track record of receiving funds.
- Require all research results to be immediately converted into no-cost, web-based Earth science curriculum for K–12 and collegiate levels.
- Provide for NASA science scholars program in partnership with major national coalitions, such as through the National Council for Science and the Environment's approximately 160 university affiliates.

NASA's participation in annual conferences for major users of Earth observation data provides perhaps the most concentrated and effective opportunities for NASA ESAP to enhance enablement of data for societal needs. Annually, over 13,000 active users of satellite and spatial data, from all walks of society, attend the ESRI (Environmental Systems Research Institute, Redlands, CA) annual user conference in San Diego. The American Society of Photogrammetry and Remotes Sensing (ASPRS) annually host over 2,000 active scientists, industry and government workers who apply Earth observations data on a daily basis in their vocations. The International Society for Photogrammetry and Remote Sensing brings multinational at-

[1] Author's analysis of trends for climate and environmental trends since the 1960s has demonstrated a consistent pattern of scientists missing tipping points until after the fact. In addition, the consensus driven process for define projections also follows a consistent pattern whereby the 'radical' projections of 20–30 years past reveal to be seen as conservative projections when realized. Examples of the Club of Rome population projections are one case in point.

tention to NASA's goals with global congress ever four years along with annual special focus meetings. NASA should recognize an implement an improved strategy for engaging with these communities as they represent the cadre of activist promoting and building upon the use of Earth observation data.

Recommendation: NASA ESAP create a comprehensive and strategic campaign to participate more fully and support the aforementioned conferences, along with a least a dozen more, for the purpose of 1) gathering intelligence on applications and user requirements for NASA Earth observation data and information, 2) foster the creation of partnerships with increased members of these communities as societal representatives, 3) identify critical and effective educational opportunities, and 4) implement a stronger brand marketing program.

2. What is involved in translating NASA's Earth observation data into information for decision-makers in Federal and State and local governments, commercial enterprises, and non-governmental institutions?

A fundamental understanding is needed as to the issue of what is referred to as "pin the tail" on the decision-makers. Decisions that affect society are mostly local and made daily by the citizens of the planet. These decisions range from carrying umbrellas to applying sun screen, to where to vacation, to what type of automobile to purchase, and hopefully to what type of proposition or political candidate to vote for in an election. This subject was investigated thoroughly by a team from GRID Arendal, Norway under the leadership of Lars Kristoferson, where a diffuse and complex reality was identified regarding the pathways environmental and spatial data and information enter the decision-making processes of society, Figure 1. A key finding was that *visualization of science data* had the most direct impact on societies and decision-making. An example was given of using Landsat data for the 200-year land use change study for the Baltimore-Washington region.[2] This science study (a collaboration of NASA, U.S. Census, USGS, and the University of Maryland, Baltimore County) provided then Governor Parris Glendening of Maryland with the visualization video that propelled the Smart Growth legislation.

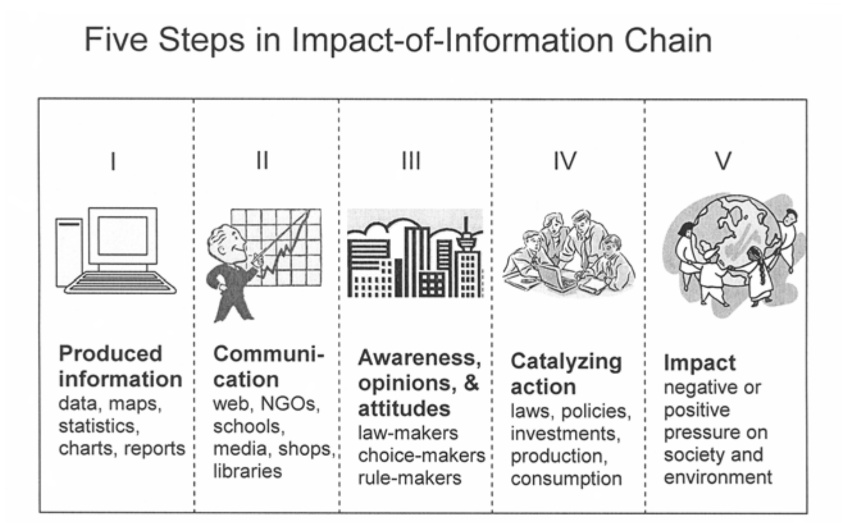


Figure 1—Decision-making Chain for Earth Observation Data and Information

Of the five steps define in Figure 1, NASA ESAP has been mostly attuned to Step 1, producing information. The litany of programs and data clearinghouses that have been designed, built, and attempted is beyond the scope of this document. Fun-

[2] Foresman, T."The Baltimore-Washington Regional Collaboratory Land Use History Research Program," in Sisk, T.D., ed. *Perspectives on Land Use History of North America: A Context for Understanding Our Changing Environment.* U.S. Geological Survey, Biological Resources Division, Biological Science Report USGS/BDR/BSR–1998–0003, pp. 33–42. 1998.

damentally, NASA ESAP has been underwhelming in its success to getting these information repositories and enterprises to push the data and information into Steps 2–5.

A compelling element of translating data and information for decision-makers is in having a deep and experiential level of understanding regarding how decisions are made in various agencies, at various levels, and among industry and NGOs. This witness has a rare background that includes managing the spatial data and information enterprises or departments at the county level, at the city level, for various NGOs, for businesses, for federal agencies (DOD, EPA, NASA), for various country ministries, and for the United Nations. This experience has taught the witness that translation by federal employees is simply not an easy task and must be learned as an art form, not an engineered or scientific script. Therefore, the most efficacious approach is to incorporate into the NASA ESAP culture and operations various veteran visiting experts from different walks of society, both nationally and international, on a frequent and consistent basis. Veteran experts can be partnered with NASA ESAP staff to work on translation issues, pilots, and other exploratory techniques. Such "interns' or visiting staff will provide for a much more cost effective approach in opposition to the numerous and costly regional workshops and seminars that have been pressed into service in the past. Fact finding workshops do not translate nearly as well as having veteran experts resident at NASA, for six months or longer, in defining and testing improved translating schemas. These expert exchange type experiences provide many additional residual benefits by broadening the NASA experience base.

NGO groups are especially poised to advance the societal benefits from NASA ESAP data and information. A flush of successes were recently highlighted at the 5th International Symposium on Digital Earth held in Berkeley, California (*www.isde5.org*) held 5–9 June 2007. General Pete Worden, Director NASA Ames, was a keynote presenter at this conference, which documented Earth observation data being used for:

- communities working to ameliorate the negative impacts of mountain removal in the Appalachian mountains,
- monitoring human rights in Darfur,
- disaster response in Indonesia and New Orleans,
- disease vector monitoring and management,
- glacier monitoring and mapping,
- biodiversity assessments,
- land cover change dynamics in South America,
- forest protection through science visualization and community engagement,
- community peace mapping and conflict mitigation, and
- marine species tracking and monitoring.

The vast majority of these examples were led by NGOs. Typically, NGOs, including those of recognized stature (e.g., Conservation International, Green Belt Movement, Heinz Center, Nature Conservancy, World Wildlife Fund) do not possess large technical staffs and rely instead on one or two geographic information system (GIS) technicians who usually import Earth observation data from various sources for their project assessments. By focusing on the functional methods to facilitate ready and free access of timely and time-series Earth observation data for locations around the planet, NASA ESAP could revolutionize its impact on society.

Success has been witnessed in a semi-random fashion regarding the educational initiatives of NASA ESAP. Many fine examples exist, including the Remote Sensing Core Curriculum (RSCC) and Conferences on Remote Sensing Education (CORSE) that were initiated in the early 1990s with seed funding from NASA ESAP. These programs were successful in part because they were based on small core groups of collaborating experts as opposed to large institutions with unwieldy bureaucracies. In addition, the education programs worked closely with other successful initiatives such as the NASA/NOAA Globe program.

3. What gaps, if any, exist between the goals of NASA's Earth Science Applications Program and the tools and processes needed to translate Earth observation data into useful applications? What, if any, improvements to NASA's Applications Program would you recommend?

NASA ESAP was once the world leader in an initiative called Digital Earth beginning in 1998. This initiative involved 17 federal agencies agreeing to cooperate, with no funds exchanged and led by NASA, on defining and creating the tools and process needed to translate Earth observation data into useful applications. The Digital

Earth initiative was heralded around the country and the world, with the Chinese Academy of Sciences embedding the program immediately into their structure and out-year planning processes. The Chinese founded the International Society for Digital Earth May of 2006 and are responsible for helping initiate the new *International Journal for Digital Earth* (Taylor and Francis Publishers). This sequence of international successes has been accomplished without NASA ESAP participation since 2001, due to political decisions made under the current administration. The reasoning behind NASA ESAP's decision to kill the Digital Earth initiative that NASA had created and nurtured, was due to the association of former Vice President Al Gore's name regarding a speech where he mentions the Digital Earth vision. Had the current administration followed the same logic with the Internet, Congress would be using alternative means of communications. This gap in NASA's judgment has had profound impacts on its ability to work with and lead in delivering the tools and processes necessary to translate Earth observation data.

Further testimony on this subject is provided from the witness's direct relationship with the Digital Earth community after leaving NASA Headquarters in 2000 for the position as Director of Early Warning and Assessment at the United Nations Environment Programme (UNEP). While at UNEP, the witness provided the first contract with the founders of Google Earth (then operating as Keyhole Inc. with four programmers). These types of entrepreneurial opportunities for more effective tools and processes for translating and delivering Earth observation data were therefore squandered by NASA ESAP and have not been recaptured. Currently, as witnessed at the 5th International Symposium on Digital Earth, a suite of organizations is refining and operating Digital Earth geobrowsers (e.g., NASA's World Wind, Geofusion's GeoMatrix, ESRI's ArcGIS Explorer, Microsoft's Virtual Earth, Google Earth, Skyline's Globe) that can and will be the primary tools for delivering data and information to decision-makers and citizens throughout the planet. NASA ESAP is not engaged in these works, albeit conversations with Google executives and Dr. Griffin (NASA Administrator) have been on going. The flaw in these discussions is that NASA ESAP is not engaged with the community, but rather has limited strategic dialogues with only one of the industry leaders and therefore is not demonstrating comprehensive attention regarding the requirement to engage with the community of developers as a whole, including its own NASA World Wind. NASA's World Wind geobrowser (an open source software platform), while internationally recognized for its technical prowess and performance, receives short thrift in financial and staffing support from NASA's administration.

The number one recommendation for NASA ESAP is to terminate the failed policy of linking Mr. Gore with Digital Earth (there is no factual link, only an historic footnote) and revisit the potential leadership role for the Digital Earth technical and user community both national and internationally. This recommendation will require immediate attention due to the ongoing dialogue with Eric Schmidt (Google executive) and Brigadier General Pete Worden and other NASA executives for a specialized center to be created with Google funds at the NASA Ames Research facility in Moffett Field, California. A NASA Digital Earth facility with full and open access by NGOs, academia, industry, government agencies and international groups should be seriously considered to address this question (#3).

The second recommendation is for NASA ESAP to join in supporting the Digital Earth Exchange (DEX) being piloted by the San Diego State University Visualization Center. The SDSU Visualization Center, under the leadership of Dr. Eric Frost and senior scientist John Graham, has been hosting the *Strong Angel Series* to demonstrate and further develop the effectiveness for open-source, and inter-operability standards in emergencies and disaster response to use multisource satellite imagery and field data for operational use. This facility has advanced the understanding of real-time data exchange and decision support among a collection of leading federal, State, industry, NGO, and academic participants (including DOD and FEMA representatives). This facility and the coalition of supercomputer nodes working in alliance with SDSU, represents the epitome of cost-effective, cutting edge technologic application of Earth observation data for web-delivery of societal priority decision support needs. This entrepreneurial enterprise is *filling in the major gaps* that exist in NASA's ESAP technology translation and applications.

4. What changes, if any, in NASA's Earth Science Applications Program are needed to implement the recommendations of the Earth science decadal survey on applications and the transition of research into operations?

With respect to the 17 missions defined in the Earth Science decadal survey, NASA ESAP is currently below capacity with the expertise for the science missions and for the defining the translation issues and capacity to provide adequate support. The current staff is required to perform heroic efforts in hours and stress to keep up with the demands while attempting to cope with the decreasing scope and quantity of sensors and missions. Land cover continuity has become a Sisyphean task with civil servants constantly engaging with community and industry experts to examine new alternatives, while the legacy of a 35-year Earth observation jewel for science is held hostage to programmatic shifts, budgetary cuts, and inter-agency politics (DOD's past role in Landsat is a prime example). **Climate change and land cover change scientists have demonstrated the unqualified success of having a time-series record of our planet's land surface phenomena.** There is no method to recreate this legacy and soon it will be demonstrated for its vulnerabilities under the present trajectory.

A prime example of the successful use of the Landsat time-series has been the recent UNEP publication *One Planet Many People: Atlas of Our Changing Environment.* This publication has sold more copies than any other environmental publication in the history of the UN. It has been translated for access on Google Earth and is changing the very way people view our dynamic world. A point in fact is the limited role that NASA played in this effort (exceptions noted for Dr. Martha Maiden, Dr. David Herring, Mr. Woody Turner, and Dr. Rebecca Lindsey who consulted on this project).

Recommendation: Institute major changes in NASA ESAP's plan of action in 2008 to take leadership in the development of land cover change products, atlases, and web-based information for every nation on the planet. This must be carefully coordinated with leading land cover change researchers and programs, such as those of Conservation International, Nature Conservancy, IGBP, UNEP, FAO, and Planet Action.

The litany of science missions define in the decadal survey portrays a serious lack of instrumentation for column measurements of greenhouse gases. Instruments have recently be identified, with solid understanding of the physics, by Dr. Robert Corell (The H. John Heinz III Center for Science, Economics and the Environment) and colleagues that would attend to the measurements and monitoring of column CO_2 and other greenhouse gases. These measurements are proving critical as the science of natural and anthropogenic gas emissions and fluxes advances. NASA's cutbacks in sensor development and missions has curtailed, if not sequestered, the introduction of new and economically feasible greenhouse gases monitoring missions and programs.

Recommendation: NASA ESAP conduct a rapid review workshop with leading geophysicists, atmospheric scientists, and instrumentation engineers to ascertain the feasibility and scoping of new instruments and missions for climate change research beyond those discussed in the decadal survey.

5. Based on your experience as a "user," and your experience in working with users, what are the most important steps NASA should take to expand the application of NASA's Earth observation data to meet social needs?

NASA will require a reinvention, or reestablishment of its mission, to include Earth as it primary planet of study and Earth sciences at its core. This shift in mission will enable the staff and collaborating agencies and entities a freer rein on educating, engaging, and enabling the real-world user communities that can benefit from NASA data, information, and services. Currently, the mission and philosophy of the Agency, demonstrated by reductions in funding and other resources, is crippling NASA's potential in these areas.

Morale of Earth science personnel has been witnessed to be significantly degraded from that of the previous years in previous administrations. It would be trivial for Congress to validate these statements by inviting various witnesses from the Goddard Space Flight Center and NASA Headquarters, or any number of other NASA facilities.

To propel NASA onto a positive stage for engaging with the user community on both a widespread and deeply integrated fashion, the following initiatives are recommended for consideration and further engagement beginning no later than FY 2008. These initiatives are not exhaustive of the opportunities available, but have been identified due to the persistence and growth in sophisticated use of Earth observation data by the user communities and for their highly visible and marketable value.

- **Green Belt Movement**—Launched by Dr. Wangari Maathai, Nobel Lauriat for Peace, to help upgrade the plight of women and communities throughout

Africa and the world. The Green Belt Movement (GBM at *www.greenbeltmovement.org*) has initiated a one-billion tree planting campaign that directly applies the satellite technology to investigate the areas of deforestation and land use degradation that require priority attention. GBM's use of satellite data and information can be directly linked to a litany of key application areas, including:

- ○ reforestation
- ○ water resources,
- ○ disease vector monitoring,
- ○ disaster mitigation and response,
- ○ food security,
- ○ women and girls education, and
- ○ biodiversity protection and management, as well as
- ○ the burgeoning enterprise of carbon for poverty reduction (CPR).

The world stature of Dr. Maathai and the potential impact of GBM is of such importance that **NASA should consider this a priority focus for engagement and support in 2008.**

- **Planet Action—**Launched on the 5th of June by Spot Image (see attached flier *www.planet-action.org*), this initiative, to focus on climate change research, relies upon application of multiple decades of time-series satellite data. Projects and programs to be associated with Planet Action will require a research component and connection with local communities impacted by challenges of climate change. Results from projects will be shared through an open, Digital Earth Exchange platform. The focus areas include:

  - ○ Vegetation, biodiversity & ecosystems
  - ○ Oceans
  - ○ Ice & snow cover
  - ○ Drought, desertification & water resources
  - ○ Human dimensions & habitation

  Currently, this initiative is engaged in collaboration dialogues with strategic partners, including the Environmental Systems Research Institute, World Wildlife Fund, Conservation International, Digital Globe, GeoEye, Heinz Center, the European Space Agency, and many others. Planet Action will be operated by a separate non-profit entity beginning in 2008.

- **Millennium Water Alliance—**This alliance was formed four years ago to enable collaborative actions for delivering safe drinking water and sanitation to the two billion people lacking access to both (*www.mwawater.org*). The leading water NGOs are cooperating but lack the technical infrastructure to enable field coordination and effective knowledge of geo-hydrologic regimes around the planet. This alliance represents a prime target for NASA to engage with and begin making real progress in applying its data and information into the existing global community.

It is sincerely hoped that through the Committee's oversight and hearings that a significant shift in focus and effectiveness can be brought to a previously renowned agency. Leadership and demonstrative results, as well as strategic engagement with key enterprises around the Nation and the world, are clearly needed in NASA. Making science knowledge actionable should become the proud tradition of NASA and the ESAP. Hopefully, the input provided by this witness may help contribute to this goal.


The three Planet Action commitments are to:
Support projects that substantiate and assess climate change impacts on a global as well as local scale and suggest local adapting actions;
Set up and manage an internet collaboration and information platform;
Use projects to communicate and educate impacted populations.
The five Planet Action main focuses are:
Vegetation, biodiversity & ecosystems
Oceans
Ice & snow cover
Drought, desertification & water resources
Human dimensions & habitation
Stand for Earth, act with us
PLANET ACTION
Spot the impacts, engage in action
www.planet-action.org
The Planet Action partners include the Earth observation and geographic information industries and institutions, NGOs, national and international organizations, as well as companies that wish to contribute to tackling climate change.
We welcome your participation
Planet Action
Earth official partner
planet-action@spotimage.com
www.spotimage.com
SPOT IMAGE
Climate Change
Spot the impacts, engage in action
Planet Action is an open initiative of Spot Image and its partners to support projects that assess climate change impacts and propose adapting actions.
PLANET ACTION
Spot the impacts, engage in action

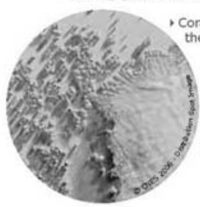
Project a change

Planet Action supports projects issued by the scientific or civil community that meet the following criteria:

- The project deals with one of the 5 Planet Action focuses;
- The team includes at least one national from the country where the project takes place;
- The project is supported by a university, public or private laboratory;
- The project links scientific observations with local action plan or adapting strategy.

Some projects in preparation:

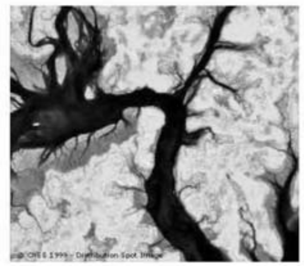
- Melting glaciers in Iceland



- Coral reef bleaching in the Caribbean sea
- Biodiversity changes in Madagascar
- Avoiding deforestation in the Ivory Coast

An International Call for Projects will be launched in 2008.

Share observations & knowledge



Planet Action will manage a unique and open exchange platform with extensive information and visualization tools about climate change.

The Planet Action Exchange Platform will be the place of choice for anyone concerned with global warming: project teams, scientific experts, media, industry, institutions, NGOs and the general public.

It will integrate:

- An openly accessible and editable knowledge base about climate change;
- Expert forums and public forums about the Planet Action projects;
- An image library that includes satellite images as well as terrain photos, from contributors and partners;
- Links with sites and initiatives about climate change.

Heighten public awareness

Planet Action envisions educating and raising awareness among a large number of communities and decision makers about climate change impacts and mitigation actions.

The Planet Action outreach program will progressively include:

- An annual Planet Action event that will represent highlights and special rewards for the most applicable projects;
- Publications about Planet Action projects and results;
- Conferences and talks by projects teams and supporting experts;
- Specific information tools for the media and education to be set up with partners.

BIOGRAPHY FOR TIMOTHY W. FORESMAN

EDUCATION

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DISCUSSION

Chairman UDALL. Thank you, Dr. Foresman, and I thank the panel for a very compelling and stimulating set of testimony.

We will now open our first round of questions. The Chair will recognize himself for five minutes.

BALANCE IN THE EARTH SCIENCE AND APPLICATIONS PROGRAM

I wanted to turn to Dr. Anthes and Dr. Barron initially. Dr. Freilich's testimony asserts that NASA's budget request supports a balanced program. Do you agree based on the recommendations of the Decadal Survey, and if not, what aspects of the program are out of balance?

Dr. Anthes, why don't we start with you?

Dr. ANTHES. Yes. I would not say it is not balanced but it is just not enough. You can see that the purchasing power, the investments in Earth science at NASA has decreased by 30 percent since the 2001 levels, and that is not enough to do even the minimal program that we are talking about. I think it is more a question of too little rather than not a balance.

Chairman UDALL. Dr. Barron.

Dr. BARRON. I completely agree.

Chairman UDALL. Dr. Freilich.

Dr. FREILICH. I thank my colleagues for recognizing the balance in the program. I point out that we operate 14 satellites now and we have seven more in development that will launch off by 2013. The size of the Earth Science budget is itself determined from a series of balance calculations across the disciplines in NASA and between NASA and other agencies. It is my job to get the best science, the best applications on the resources that are made available.

Chairman UDALL. I thank you for that succinct and to the point set of answers. I think we may turn back to this at some point later in the hearing.

STRATEGIES TO MITIGATE THE IMPACT OF CLIMATE SENSORS REMOVED FROM NPOESS

I do want to turn to NPOESS, Dr. Freilich, and talk a bit about the status of the strategies to mitigate the impact of removing the climate sensors from NPOESS. Maybe I will leave that as an open-ended question to you and ask you to respond.

Dr. FREILICH. Okay. Thank you. As you know, it was just about a year ago when because of a series of technical and budgetary issues the NPOESS program was refocused on its core weather forecasting objectives, and that resulted in the demanifestation of several climate sensors and degradation of some others which are important for the Nation's scientific and applications programs. Almost immediately after that and before I joined NASA at headquarters, NASA and NOAA working together with the Office of Science and Technology Policy began an in-depth study of the climate impact of those demanifestations and degradations, and that was presented in early January, and we ranked from that the top measurements that were required to be remanifested based on science issues, and you are well aware of that, and we are moving forwards to that. Subsequently, we have been working with NOAA and OSTP in order to develop mitigation scenarios and associated costs, and this is a work in progress still in order to get those capabilities back in a realistic schedule, a realistic budgetary environment and addressing the science and the applications. In April, NASA and NOAA got together and jointly funded the remanifestation of the Ozone Limb system on the NPOESS Preparatory Project. So to sum up, we are working very, very closely and very intensely with NOAA under OSTP guidance to understand the impacts of the Nunn-McCurdy refocusing and to develop scenarios to regain those capabilities.

MAINTAINING CLIMATE INSTRUMENT TEAMS

Chairman UDALL. Could I ask more specifically, what are your plans for maintaining the teams developing the climate instruments such as the TSIS as you do the work to find mitigation strategies and the way forward?

Dr. FREILICH. In the area of—for instance, in the area of total solar irradiance measurements, the Glory mission, which will be launching late in 2008 or early 2009, is primarily an aerosol mission but it also includes a total solar irradiance monitor, which will continue that time series which is critical to have on-orbit overlap. So in many instances, some of the measurements and missions that we have under development now will continue and extend those time series and those teams are in part participating in the development of those missions.

Chairman UDALL. Thank you. My time is expired. I am now pleased to recognize Mr. Feeney for five minutes.

Mr. FEENEY. Well, thank you, Mr. Chairman.

NASA'S PLANS WITH RESPECT TO RESOURCES

Dr. Anthes, Barron and Foresman, you have heard Dr. Freilich's testimony about NASA's approach going forward. Given the fact that we have some limited resources and there are constraints that all three of you are concerned about, given that reality, do you think that programmatically NASA is taking the appropriate steps and do you have any guidance for NASA, again given the reality of the limited resources that you pointed out?

Dr. Anthes, why don't you start?

Dr. ANTHES. I think we have given NASA about all the guidance that they need at the moment through the Decadal Survey. That was a two and one-half year study by over 100 people. But again, I get back to the point that NASA is doing a good job with what they have but they just don't have enough, and for—you know, we are talking about just going back to the 2001-2002 level, that is $2 per person per year in the United States. That is the price of a bad cup of coffee. And so I think this is affordable. I mean, this is not an unreasonable request to ask for—to NASA to ask the Administration or the Administration to ask Congress or Congress to supply the resources needed to do our minimal recommended program.

CONTINUITY OF CLIMATE OBSERVATIONS, DATA GAPS, AND SENSOR CALIBRATIONXXXXXX

Dr. BARRON. I would like to just add to that that I think we have to find a way to fix this issue of climate continuity of these observations so that every time it is not a stopgap effort. There were a large number of reports and a large amount of effort that suggested that NPOESS was going to present problems for climate quality observations and it is as if each time your worse nightmare arrives one more time and you go through—you go through this and even in writing the Decadal Survey, it was like a moving target to watch things dropping off and questioning what was going to happen and how it was going to be done and now we are going to add studies. We are going to take a solar measurement that gets us part of it but not everything. Each one of these components in terms of this record will be examined but nowhere in there I think is the sense that we are actually going to fix this so that we can actually sit here and argue about how we are going to make improvements and advances, how we might be able to save money through efficiencies, how we might be able to do a better job of designing an observing system because instead the most basic and fundamental set of observations for the climate system are in jeopardy one more time, and so I think that a lot of analysis on how to maintain parts of that is not the issue. We have a bigger issue to fix.

Chairman UDALL. Dr. Foresman, you have to push——

Dr. FORESMAN. Thank you. I certainly agree with their comments. I would relate mine to the other 95 percent of the community outside the scientific domain in terms of I feel that NASA could do much better in terms of being able to connect and outreach with innovation, industry partnerships, academic partnerships and NGO partnerships that heretofore have not been made available, but again, as I emphasized, the technologies that are now changing the landscape are but two years old, and if NASA is not prepared within their staff and experience at the current time to address how that strategically impacts what they should be doing to deliver to every district in this nation and citizens that lie within there.

Mr. FEENEY. Dr. Freilich, given Dr. Barron's point about the continuity of some of the programs, there is a risk that some of our current satellites that are operating well past their design life may expire before replacements are launched. How serious would the consequences of a data gap for a year or two be in terms of our mission and talk about the risks of calibrating new sensors in terms of that continuity that Dr. Barron was concerned about.

Dr. FREILICH. I could deliver a lengthy treatise as my academic background is asking me to do but I will refrain from that for your benefit. The need for continuity and the approaches to calibration and validation either on orbit overlap or vicarious calibration differ from quantity to quantity and measurement to measurement. Let me focus for an illustrative example on total solar irradiance. We have a 23-year-plus time series of measurements of the sun's broadband output. We can make very, very stable and very sensitive instruments but we can't absolutely calibrate them on the ground. Therefore, it is essential for that measurement that we have on-orbit overlap of six to 12 months so that the time series can be made consistent and we can understand whether changes are owing to the changes in the sun or changes in the instrument when we weren't measuring and therefore, for instance, that is why we have put a total solar irradiance monitor on the Glory mission, which is due to launch in late 2008 or early 2009 to assure overlap with our existing instruments, for instance, SORCE. Consistency and continuity, where our understanding and our predictions are sensitive to it, is number one on our list because it is essential for us to redeem the Nation's previous investment in these time series by continuing them where necessary. In some areas we could survive with a gap or a degradation and do calibrations using transfer standards.

Mr. FEENEY. Mr. Chairman, my time is expired but if the chairman would agree, I would just like to get Dr. Barron to respond to that because it is a concern that you raised and you think that this is—what do you think of Dr. Freilich's response?

Dr. BARRON. He has provided a good answer and it is true that different rules and needs apply for different sensors but if you can imagine for me a minute having a system in which we say oh, we are about to lose this because it didn't work here, let us go do something over here, or if something fails and then make a decision that you are going to do something, that is not a very robust system, and we have been arguing about how robust the system is and what needs to be done to make it more robust for at least 20 years, it seems to me, and it strikes me that we are in worse shape, not in better shape, in terms of designing that as a system. So I agree that what he said is correct but I do not think that embodies a strategy of how to put this problem aside so that you are not continually addressing what you need to do and what you need to add because you have lost something here.

Chairman UDALL. Thank you, Dr. Barron and Dr. Freilich.

We will now recognize the gentleman from Texas, Mr. Lampson, for five minutes.

Mr. LAMPSON. Thank you, Mr. Chairman.

I think I share some of the frustrations that all of our colleagues are starting to express more and more, and Dr. Anthes, I think I would have probably not said nearly as nicely as what you did about resources. We keep hearing time and time again the comments that NASA and other agencies as well make the best efforts possible with the resources available. I think that is a huge copout and there are budgetary issues but we are teaching this nation to not understand about science. We are teaching this nation that we are not going to get a return if we invest in something that will tell us something about our future, and the return is huge, and I was sitting here thinking that this little statement behind me, how indeed true that it is, that if we don't step up to the plate and exhibit the political will and quit copping out to those who are leading us without that vision—we can talk words but we have to implement it, act on it, and I think there is an interest on the part of our Congress to do that. We need guidance from the science community, we need guidance from this public, and the public itself needs to be taught, I believe, how to respond to us so that we can become the followers of them and hopefully put the resources where we need them. I am going to try to ask a whole bunch of questions in a very short period of time so short answers, please, gentlemen.

TRANSITIONING RESEARCH SATELLITES AND MEASUREMENTS INTO OPERATIONAL SYSTEMS

Dr. Freilich, the Earth Sciences Decadal Survey discusses the need for transitioning research satellites and measurements into operational systems. The *NASA Authorization Act of 2005* calls for NASA and NOAA coordination on research to operation. How often has NASA–NOAA joint working group met and when was the most recent meeting?

Dr. FREILICH. The joint working group, which is one of many specific groups, met twice during 2006, and I believe that the most recent meeting was in April of 2006. It was a multi-day workshop. However, there are many other meetings periodically that we have and regularly. There is a tri-agency altimeter working group, and as I pointed out, NASA and NOAA have gotten together and remanifested the OMPS–Limb sensor on——

Mr. LAMPSON. This committee met a year and a half ago almost. What specific issues has it addressed?

Dr. FREILICH. The joint working group has five specific issues that it addresses and it focuses on transition of measurements, transition of missions that are on orbit and issues associated with data set, stewardship and climate records.

Mr. LAMPSON. Is the joint working group with NOAA able to effectively plan for transitions from research to operations?

Dr. FREILICH. We face a real challenge as a country in doing that transition and there are very few successful and rapid transitions. However, with guidance from the National Research Council—and Dr. Anthes in fact authored the CONNTRO report to the Committee on NASA–NOAA from research to operations. People at NASA and at NOAA are very sensitive to this issue. The National Research Council has set out a path forward and the joint working group and the other working groups are leading us along that path. We are making progress.

Mr. LAMPSON. Would any of the other witnesses care to comment on any of those questions?

Dr. ANTHES. It is a very good question. It is a very tough problem, this transition from research to operations. I hate to keep whining about not enough resources but, you know, it takes resources to transition these new technologies into NOAA operations, and NOAA's budget has been relatively flat, even declining, and they simply don't have the resources to transition even the simplest, even some of the cheapest new technologies into operations. So this is a really big issue, as Dr. Freilich says, and we just have to come to grips with there is no plan, there is no national plan, it is not going well. Partly it is due to the fact that NOAA doesn't have the resources to take on these huge responsibilities and so it is not just simply one agency problem. It is a two-agency problem.

Mr. LAMPSON. The yellow light is on. If I start into this, it is going to take me a few more minutes, so I will yield back my time now and——

Mr. FEENEY. If there is no objection. Go ahead.

Chairman UDALL. Mr. Lampson, why don't you take a couple more minutes?

Mr. LAMPSON. Thank you very much.

FOLLOW-ON TO NASA'S QUIKSCAT SATELLITE

For Dr. Anthes and Dr. Barron, according to a recent article, scientists exploring options for QuikSCAT success in *Space News,* the new director of the National Hurricane Center has emphasized the need to plan for a replacement to NASA's QuikSCAT satellite should it fail. The Decadal Survey proposes a follow-on to QuikSCAT but not until 2013 at the earliest. What is the reason for the timing of the Extended Ocean Vector Winds Mission, XOVWM, and how urgent do you believe the situation with QuikSCAT is?

Dr. BARRON. I think you see that what the Decadal Survey did was put a whole group of very important missions on the table and at the same time we tried to live within a very specific budget constraint which wasn't give us more, give us more, give us more, it was get us back to where we were in 2001 and 2002. Now, you only have one choice there. You have put a list there and you have to put them in time, in some sequence and so you will see that one particular mission that focuses on one critical topic is delayed to a later date because of hope that something will continue or because something else in another part of the world is going to contribute some information, but there really was within that envelope no choice and I think what you see too is, there is nothing added to that in terms of true innovations on that list. It is just basically to fit things in as best we could that were critical. At least that is my view.

Dr. ANTHES. I can only add a little bit to that. There is a European scatterometer in place called ASCAT, which although not providing the level of accuracy that some people would wish at least is an interim scatterometer that will provide some of the information needed for the ocean vector winds that are important for hurricane forecasting.

Mr. LAMPSON. And we are also going to rely on the Russians for moving our men and women to and from the International Space Station, and who else are we going to be relying on into the future? What advances would the XOVWM mission offer over QuikSCAT? And I am going to ask——

Dr. ANTHES. This is his—he is an expert in scatterometry so he should——

Dr. FREILICH. I am very proud of QuikSCAT. I was the mission principal investigator for it so allow me. The XOVWM mission that was recommended by the Decadal Survey primarily has higher resolution in space so it measures more fine short-scale variations in the wind field and it will have the ability to make measurements that are accurate under raining and severe conditions which present systems cannot do. So we will be able to get closer to the coast. We will be able to measure smaller-scale wind variations when the NOAA XOVWM mission flies, and we will be able to make measurements that are accurate under extreme conditions and rain.

Mr. LAMPSON. My last thing, and it is short and I appreciate the indulgence of the Chairman and Ranking Member, I sent a letter regarding the NASA–NOAA research to operations working group report asking for that. It was supposed to have been here on February 15. NASA sent it for clearance, I think, earlier this month. Do you have any idea when I might be able to expect delivery of that?

Dr. FREILICH. I am relatively new to the Federal Government and I am learning a lot. I can tell you that substantive work on the text of that report ended many, many weeks ago and it is working its way through the agency and interagency review process. I will take an action to get back to you. I think that it is imminent but I can't say with certainty. I am sorry.

Mr. LAMPSON. My fear is that we have become such a—almost a bloated bureaucracy that we can't move and somehow, I think as some of you have stated, Dr. Foresman and others, we have got to find a way around that. We have got too much at stake for our future.

Thank you, Mr. Chairman.

Chairman UDALL. Thank you, Mr. Lampson. That was a very important line of questioning, and Dr. Freilich, I hope that you will respond to Dr. Lampson—or Mr. Lampson as soon as possible. There is a Dr. Lampson. It turns out it is Nick's brother.

TOTAL SOLAR IRRADIANCE SENSOR (TSIS)—MAINTAINING THE TEAM AND POTENTIAL INCLUSION ON LANDSAT DATA CONTINUITY MISSION

If I could, Dr. Freilich, I want to go back to the discussion of climate instrument teams. It is my understanding that the Glory instrument contracts are winding down, as important as that project, set of projects is. What specifically will NASA be doing to maintain the TSIS team for the remainder of 2007—fiscal year 2007 and through 2008 while OSTP is deciding what to do?

Dr. FREILICH. I can't give you any specifics, sir, beyond the fact that although the contracts—although the work, the development work on those instruments—that instrument is in fact winding down, because the instrument is being built and successfully delivered and integrated, there still remains a lot of work for integration tests and maintenance of that followed by of course after launch validation and calibration and characterization of the instrument. I don't have the specific information that I can give you on TSIS. Again, we can find——

Chairman UDALL. Do you have an idea when you might have that specific information?

Dr. FREILICH. As soon as I can get back and within a couple of days I will make inquiries. I am sorry.

Chairman UDALL. That is terrific. Thank you.

Let me continue on the TSIS line of questioning in the context of some broader concerns. NASA officials have indicated that the Landsat Data Continuity Mission is being considered as a potential platform for TSIS, and how about a sense of when a decision might be made on that option and how would adding the TSIS affect the LDCM schedule and the duration of any potential gaps in the land cover data record?

Dr. FREILICH. You have hit the high points, Mr. Chairman. You are well informed. The Landsat Data Continuity Mission is designed principally to extend the 30-year-plus record that we have of moderate-resolution radiometry over and imagery of land surfaces. It has been an incredibly valuable data set. At present we have two spacecraft both flying well beyond their baseline lifetime. LDCM is scheduled for launch at present in mid-2011, designed specifically to minimize the gap, and I am afraid that we will have a six to 12-month gap in that long time series. We are looking at using that platform potentially as you said to extend some other critical time series such as TSIS. The number one issue that is guiding us there is in fact the schedule and the risk for minimizing the gap on the time series of the land imagery. We are looking at lots of options and again that work is deeply underway and has been for several months. We are letting four contracts for LDCM and they are in the process of being advertised right now and the interaction between them and the technical addition of TSIS will govern our schedules and our decisions.

CLIMATE MEASUREMENTS AND 'DECADAL SURVEY' MISSIONS

Chairman UDALL. Let me follow on here. What role, if any, will the Decadal Survey missions have in addressing any potential gaps in climate and environment measurements as a result of the Nunn-McCurdy restructuring at NPOESS?

Dr. FREILICH. If I understand your question, it is can Decadal Survey missions fill in for potential NPOESS demanifestations. Do I have that correct?

Chairman UDALL. That is fair enough.

Dr. FREILICH. Okay. The Decadal Survey actually was, as Dr. Anthes and Dr. Barron said, was very careful in not overlapping capabilities for the Nation so in fact the problem turns out to be almost an opposite one, that is, the NPOESS refocusing happened late in the Decadal Survey process and many of the Decadal Survey missions actually rely on measurements that were to be taken by NPOESS as opposed to duplicate measurements that would be taken by NPOESS and one of the goals of our workshops is to actually understand what contextual measurements that would have been made by NPOESS are necessary for the Decadal Survey science so that we will advance the science.

Chairman UDALL. Perhaps I could just take another minute and ask Dr. Anthes or Dr. Barron if they care to comment on the last question.

Dr. ANTHES. Well, there were two recommendations for NOAA in the very early time frame, the 2010 to 2013, that have great bearing on climate. One is the CLARREO mission, which is to do benchmark climate radiation observations. The climate fundamentally is warming because there is an imbalance between what radiation we are receiving from the sun and what is being either reflected back or emitted back and so we need a set of benchmark radiation observations that will measure not only what the sun is putting in but what is being reflected back and what is being emitted back from the Earth. The other instrument that is recommended in this very early time frame is the GPS radio occultation measurements, which make very accurate and precise measurements of the temperature and water vapor structure of the atmosphere. Again, these would be benchmark climate observations that will tell us how fast the atmosphere is warming up, where it is warming up the fastest and how the water vapor is increasing regionally and globally. So these are two relatively inexpensive missions that can be launched by 2010 and will contribute to the very essential climate observations.

Chairman UDALL. Dr. Barron, anything else to add?

Dr. BARRON. Yes, those—I completely agree with Dr. Anthes. Those are extremely important. And I would also, you know, like to confirm what Dr. Freilich said. As Chair of the climate panel, we sat there with an assumption that we had a basic set of observations long planned through NPOESS that would continue and that our objective was to build upon that. Where are the great uncertainties in climate models? How can we make observations to make improvements? And in particular in the latter half of the Decadal Survey, every meeting of my panel it seemed we had to reassess what was the base that we were building upon because we were moving from a situation of instead of proposing innovative ideas to tackle important problems, we were trying to make sure we were going to not lose what we have had for decades.

Chairman UDALL. Thank you, and Mr. Feeney is recognized.

Mr. FEENEY. Thank you, Mr. Chairman.

INTERNATIONAL COOPERATION, INCLUDING CHALLENGES OF ITAR

Congressman Lampson raised the international reliance and cooperation issue. Dr. Freilich, obviously there are some advantages including avoiding duplication of services and reducing costs with cooperation. Your statement suggests that there are some bilateral discussions underway with several partner agencies. Is the concept to have other countries assume full responsibility for designing, building and operating individual missions and then sharing the data or to have one or several partners participate in individual missions or is it a combination? I guess it would be helpful to, you know, see where we are going with the bilateral agreements.

Dr. FREILICH. Excellent point. The answer is, it is a combination. First let me say that the Decadal Survey very specifically points out the need to leverage our capabilities with those of our international partners. It points out that the scope of the problem and the scope of the solution is far greater than what any single agency or any single country can do. It turns out that our Decadal Survey scientists are completely in line and leading in fact the global climate science and Earth systems science community so our aims in NASA are well aligned with the aims of our partner agencies in other countries. Having said that, in many of our discussions we are talking about contributions from an instrument standpoint from multiple countries to a particular mission but we are also spending extra amounts of time to talk about trading missions. If a mission can be flown from a particular country and the data are freely available and well characterized, then it aids everybody in our analyses and therefore we don't have to duplicate those measurements simply to say that we were making them as well. The resources are limited, the problem scope is large and we really have to have unique application of our resources, not duplicative. Having said that, we are trying all possible permutations.

Mr. FEENEY. And as you enter and participate in these negotiations, how will ITAR regulations hinder or impede your efforts?

Dr. FREILICH. ITAR presents challenges. We conform with the ITAR regulations and I am intimately familiar with several international collaborations. Like I said, ITAR presents challenges but we can surmount them. We are going to be flying, for instance— we have altimeter missions joint with the French agency CNES that have been very successful and we will be launching OSTM in June of 2008. We will be flying the first ever sea surface salinity measurement mission with our Argentine colleagues' space agency CONAE, and that will be launching in the 2009 time frame as presently listed. So ITAR is challenging but it can be surmounted and we do obey the ITAR regulations.

Mr. FEENEY. And finally, Dr. Anthes, you have mentioned some of the international cooperation components to accomplishing the overall goals. What do you think about ITAR and the potential hindrance it poses?

Dr. ANTHES. As Dr. Freilich said, they can be significant, and then some kinds of technologies they can actually prevent international collaboration. International collaboration, as I said, is—we have to consider that carefully but at some point, I think as Mr. Lampson implied, the United States can't rely entirely on other nations to make these critical observations. It would be a little bit like having a military that relied on international partnerships. We certainly need to do some partnerships but I think that some of these key observations we cannot assume that these partnerships will be there or will be successful.

Mr. FEENEY. Thank you. I appreciate everybody's testimony and I yield back my time.

Chairman UDALL. Mr. Lampson.

Mr. LAMPSON. Thank you, Mr. Chairman.

We also have to be real cautious, I believe, with our international partners when we enter into arrangements. There seems to more and more opportunity for us to find some way to renege in some of those. One I have in mind that doesn't impact any of you, the AMS Project, which is a $1.2 billion project that has been 95 percent paid for by international partners, and our promise was to put it on the space station, and at this point it is no longer on the manifest to be able to go to the space station. Those folks are not happy campers. And so if we expect to be able to enter into these arrangements, which I think are critically important, I don't see how there is any better way for us to build friendships than by working on things that benefit the people of both or more countries. We just have to be able to be cautious with what we do, what our plans are.

I don't have a question in any of that. I think I started a rant a little while ago. I love NASA. I love the science agencies that we have in this nation and I want to do things that can bring attention to the magnificent accomplishments that they make and people that have the bright minds that are making those and to continue to be able to support them in a bigger and better way. I think it is important for us to point out that right now NASA has a budget that is six-tenths of a percent of the Nation's budget, and in the 1960s when we were having magnificent achievement in education and in technological advances, the budget for NASA was six percent of our nation's budget, a significant difference in commitment, and that is something that I hope and pray that we can get back to as a Congress, as a nation and as a scientific community, and with that, I yield back my time, Mr. Chairman.

Chairman UDALL. Mr. Lampson, I might ask you to yield. We could use a little bit of your time. I know we have had conversations about the AMS Project and the important work that would be done in this very fascinating area of antimatter and I think we have some opportunities in July to question NASA about their plans in this regard. Gentlemen, I look forward to working with you to further understand why we can't see that this important project be undertaken. I think you and I have some additional plans to pursue this.

Mr. LAMPSON. Indeed, and I appreciate your interest in it but I tried to mention that only to let it be a part of this big picture of what we are not doing right now. There are too many times when we take and make the excuse of we can't get the resources to do something. If it is important for us as a Nation, as a people, we ought to find the resources. We did once before and we got an unbelievable return for it, and that is what I am looking for. That is what I want to see my government doing for this nation. It is within us. We have got to have the leadership to make it happen.

Chairman UDALL. I thank the gentleman for yielding to me and I would yield back to him if he——

Mr. LAMPSON. And I will yield my time back. Thank you, Mr. Chairman.

Chairman UDALL. I thank the gentleman. The Chair will recognize himself for five minutes.

PLANS FOR FUTURE OBSERVATIONS SYSTEMS TO ADDRESS SOCIETAL NEEDS

I did want to return to Dr. Freilich but also give Dr. Foresman a heads-up that we haven't been ignoring him and I wanted to give him an opportunity to comment on the question I am going to ask Dr. Freilich. What I want to focus on was the Academy's survey, the Decadal Survey stressed the need for observation systems to look at both scientific and societal needs, and I want to just give you a chance to talk about NASA's planning process for future observation systems takes into account this important area of societal needs. When you are finished, I would like to give Dr. Foresman an opportunity to comment as well.

Dr. FREILICH. Our missions are the basis—they provide the hard measurements and the information. The research and analysis program develops scientific-based understanding of the Earth as a system using modeling as well as those measurements. Our Applied Sciences program serves as what I call a flexible bridge between the knowledge that we gain in the research and analysis program and the need for focused information to address societal benefit areas and very specifically, our Applied Sciences program is designed to further that communication between the science understanding that is driven by the missions and the need for services and information by others who are dealing specifically with societal benefit areas. The focus of the Applied Sciences program is becoming aligned with US GEO, the Group on Earth Observations, and their nine societal benefit areas. In each one of those areas, we have pilot projects in which we demonstrate the utility of the NASA measurements and understanding to further other agency and other organizations' goals in their—for their objectives. So very specifically, the Applied Sciences program forms that connection between the science and the societal benefit areas. We are aligned with US GEO, and as I pointed out, we are playing a very key role in the international Committee on Earth Observing Satellites which is the coordinating arm for the global GEO.

Chairman UDALL. Thank you. And I want to turn Dr. Foresman and I think particularly ask Dr. Foresman to outline some examples of how this very powerful technology can be used. I had obtained recently, Dr. Foresman, a radio story about Darfur and how actually satellite imagery could help us understand on a real-time basis what was happening there and would help us expand our efforts to prevent what is clearly genocide and a very tragic situation from further developing, and I know you had some other examples in your testimony. So the floor is yours.

Dr. FORESMAN. Thank you, Mr. Chairman. This also tends to reach into issues of international cooperation as well, so it is not just restricted to the United States. We are sitting at a profound point in history where we can view these various radical, if you will, changes in terms of land use or humanitarian issues around the planet with regular citizens being able to engage. This is something that the Applied Science program, again with due respect, having been in that program and I know they did a lot of very good things but the bureaucratic realities tend to basically dilute the ability to provide rapid response, and rapid response is occurring in a variety of sectors at a rate which we talked about into the hundreds of thousands of projects that are showing up around the planet that unfortunately is beyond the scope of NASA headquarters to address. However, by restructuring, it could have the potential to address this in some very significant ways. You know, we are looking at deforestation issues. While searching for better algorithms for carbon, sometimes the academics spend time sequestering their information to be published while the forest has been removed and so they come back and they find out that it is a moot point, and this happens continuously. Reporting on how many trees are there is a phenomenal area that we are still abjectly behind the ball. Recently one of the applications was done in Santa Cruz, not known as a developing nation but Santa Cruz, California, where they were able to save 1,000 redwood trees in the backyard simply by providing through these various visualization tools that I am speaking of that NASA was the leader in showing the community what was going on with 1,000 trees that had been promulgated through the official channels as but a clear—a logging exercise by the watershed district. Well, it was a clear-cutting exercise to gain monetary benefit to a watershed district. This is a phenomenal thing, 1,000 acres of redwood trees right in the backyards of some of the most literate and intelligent people on the planet. So these kinds of examples are showing up and we captured many of those in Berkeley with General Pete Worden, who was there in Berkeley just two weeks ago with me highlighting many of these examples, and it was interesting because the Google executives admitted—and it wasn't just Google, you know, I don't have stock in that company—admitted that they can't even contain what is going on. This is an uncontrolled experiment. Well, it is an experiment that NASA should be controlling as best they can because it is the absolute soft spot. It is where the rubber meets the road in terms of how to transfer our science and knowledge into the backyards of citizens. And so we have a choice. There is two paths. We can sit back and say well, it will happen and let us watch what happens, or we can say, no, this is the time for leadership and to really gain the upper hand in these application areas because they are so profound in terms of mountaintop removal, for our energy resources in our country in terms of the governance by indigenous people that are taking over water quality monitoring and sampling from the USGS and EPA in a very profound way and a great example of the communities taking on the responsibility for stewardship in the backyards, and the tools are there now that we only dreamed of seven or eight years ago. They are here now and they are not part of the plan. Thank you.

Chairman UDALL. Dr. Barron, would you like to comment as well?

Dr. BARRON. I would. I think it is an extremely important question, and to be perfectly blunt, I view the applications program side of NASA a decade ago as throwing data over the transom and finding out who might grab it. I view the current program as one which is directly throwing data over the transom where you are sitting there looking at a particular application use and making sure that the data is available. But I think we forget the fact that there is actually a science that needs to be accomplished to make the societal connections. You are sitting right now in a world in which climate variability is having a big influence in something like West Nile virus delivered by a mosquito yet you are sitting there analyzing where and how to respond in hindsight by collecting numbers of dead birds and testing them when we have the capability to actually couple the science and human health sciences together so that you actually start to forecast the outcomes for something like a Dengue fever or a West Nile virus. We have that capability in the short-term and the long-term if we can put the communities together and to begin to set up the types of observations and modeling that you need to do it. And by collecting observations and sitting there thinking just as a climate scientist, you are not going to make that accomplishment. You actually have to bring these societal connections to the forefront and not one which is a handoff of data but one that actually promotes scientific discovery and brings that same discipline of forecasting that we apply to weather forecasting to something like human health forecasting.

Chairman UDALL. The two other Committee Members that are here inform me they have no additional questions. I did have one additional line of questioning I wanted to direct to the panel, then we will draw the hearing to a conclusion. I will turn back to Dr. Freilich but I would like everybody else on the panel to feel free to comment.

NASA'S FUTURE EARTH OBSERVATION MISSIONS AND INTEGRATING DECADAL SURVEY RECOMMENDATIONS, NPOESS CHANGES, AND INTERNATIONAL COOPERATION

Your testimony indicates that NASA's plan for future Earth observing missions will integrate the scientific recommendations of the Decadal Survey, the ongoing NPOESS Nunn-McCurdy changes and the contributions of our international partners. That is no small task. Could you explain in specific terms how you plan to actually make that integrated approach a reality, and then if I could thrown an additional two questions at you: What is the timeline for that integrated plan and how does that timeline address any potential data gaps as a result of the restructuring, the Nunn-McCurdy restructuring of NPOESS? If you want to provide some of this for the record, we would be happy to indulge you in that way well, but if you want to take a shot right now, I would appreciate it.

Dr. FREILICH. Okay. I will take a shot at that. Before I start that, may I have your lead to address the timeliness of some of our Applied Sciences projects or——

Chairman UDALL. Sure. Please.

Dr. FREILICH. Dr. Foresman made a very good point about the need to be timely in order to actually have real benefit, and Dr. Barron talked about throwing directed or undirected data over the transom. We have some real shining stars of projects in the Applied Sciences program and I would just like to talk about two or maybe one to start with, the SERVIR node, which is a data environmental monitoring synthesizing and distribution center that we in Applied Sciences have set up in Central America to bring in not only NASA data but also models from other agencies and to provide the information that is necessary for decision-makers in the Meso American area to actually manage the environment and to understand. Just last month, I think it was around the 18th of May, we were contacted by the environment ministry of Honduras where there was a degradation in air quality and it was unclear whether this was being caused by Saharan dust—they knew that there was Saharan dust in the area—or whether it was being caused by smoke, and the response in Honduras and Nicaragua and Costa Rica would be quite different. In just a matter of four days, SERVIR took data from our flying satellites, including the relatively recently launched CALIPSO satellite which measures aerosols and clouds as well as data from MODIS, combined that information with models, models of smoke distribution, fire distribution, et cetera, many of which were generated in the United States, and provided a clear description to the affected areas that in fact there was dust but it was located well to the east in the Caribbean and the degradation of air quality that they were seeing was resulting from fires which were relatively local, at least to Central America. The point being that in that very short amount of time, that NASA-sponsored project could provide the specific information that was flexibly needed by that ministry.

Okay. Now let me answer your questions. Sorry about that. It is a big task to pull together the international collaborations, the NPOESS response and our increased understanding of the technical and cost challenges of the missions. We are working on a time scale that is focused informing the fiscal year 2009 process because the Administration's fiscal year 2009 budget process is the first one that is going to be fully looking at the detailed recommendations of the Decadal Survey. I have been on the road almost constantly for the last couple of months speaking with our international partners and bringing together some of those joint science working groups. We actually even started some of the concept studies to look at technical challenges and costs a little bit before the Decadal Survey came out. They have all reported to us once and we are in the final stages of rationalizing those inputs and it is our hope—and you know what is happening with the NPOESS–OSTP–NASA–NOAA joint deliberations. They are all focused on coming up with at least the outlines of a plan and the associated resources in order to inform the Administration's development of the fiscal year 2009 budget process. So we are moving towards a fall—we are moving towards a fall coalescence or synthesis for the integrated.

Chairman UDALL. Dr. Anthes or Dr. Barron, did you have any interest in adding additional commentary to that?

Dr. ANTHES. Well, I think it is good that they are seriously considering the Decadal Survey but it is going to take more than rebalancing, more than considering, more than a few workshops. Mr. Lampson is right on. This country can't afford not to do it. There is a cost for doing nothing. We are talking about, I mean, some lag—to stabilize greenhouse emissions in the United States might cost $30 billion. That is just annually. Is that going to work? How do we know that is happening? Are we going to invest $30 billion in something that won't work or we can't observe or can't verify? What about China? China is the greatest greenhouse gas emissions country right now. How do we know what they are doing and whether what we will do will make any difference compared to what they do? So the cost of doing nothing is huge. The cost of getting on with observing this planet is very, very small. We just have to do it.

Chairman UDALL. Thank you very much.

Dr. Barron, do you want to have the last word or should we leave Rick with it?

Well, thank you all today for taking your valuable time to appear before the Subcommittee. We look forward to future visits on the part of all of you.

At this point I want to announce if there is no objection, the record will remain open for additional statements from Members and for answers to any follow-up questions the Subcommittee may ask of the witnesses. Without objection, so ordered.

The hearing is now adjourned.

[Whereupon, at 11:30 a.m., the Subcommittee was adjourned.]

Appendix:

ANSWERS TO POST-HEARING QUESTIONS

ANSWERS TO POST-HEARING QUESTIONS

Responses by Michael H. Freilich, Director, Earth Science Division, Science Mission Directorate, National Aeronautics and Space Administration (NASA)

Questions submitted by Chairman Bart Gordon

Q1. Is there a consensus (among federal agencies, academia, and other users) on a set of climate and environmental measurements to which the nation should commit for sustained observations? If so, what is the set? If not, should there be such a set of consensus measurements and what would be involved in reaching consensus?

A1. There is a National consensus on the set of climate variables documented in the U.S. Climate Change Science Program CCSP Strategic Plan, which are similar to the internationally agreed-upon set of Essential Climate Variables of the Global Climate Observing System (GCOS) of the World Climate Research Program (WCRP). The set is made up of approximately 40 different climate variables covering oceans, atmospheres, the cryosphere, the biosphere, and chemistry.

Overall, the science community has defined a relatively complete set of variables and associated observation accuracy for each variable. Several reports have also considered and documented the required accuracy, stability, and overlap of observations of these variables required to observe climate forcing, responses, and feedback (e.g., the U.S. multi-agency report from NASA, NOAA, EPA, and NPOESS Ohring et al., BAMS September 2005; and, the international GCOS Satellite Calibration Requirements Report). While the current observing systems are not fully capable of meeting these requirements, the recent National Research Council (NRC) Decadal Survey recommended specific mission priorities to address this lack of full capability. In addition, efforts are underway in NASA's research program to develop new methods to prioritize climate observations using Observing System Simulation Experiments (OSSEs), a concept analogous to weather prediction OSSEs, but based on climate model physics and the ability to use climate observations to determine uncertainties in climate model predictions.

Q2. The value of Earth observing satellites lies in the data and measurements they collect. Will implementing the Decadal Survey's recommended missions require changes to NASA's data management systems? If so, what are your plans for making such changes?

A2. NASA's Earth Observing System (EOS) has developed an extensive data system architecture capable of handling data ingest, processing, quality control, validation, archive, and distribution. The system is distributed across major data centers as well as smaller data systems. The size of the systems is determined by data volume, processing complexity, and user community needs. This distributed system has been found to be the most robust and efficient method, and keeps data processing as close as possible to the scientific expertise needed in its creation, validation, and quality control.

The missions recommended by the NRC Decadal Survey for Earth Science have similar overall data requirements, compared with NASA's current EOS and Earth System Science Pathfinder missions, so they would be handled in a similar architecture to the current NASA satellites. Many of the NRC-recommended satellites do have large data rates and processing requirements, so they will represent significant extension of capability at current data centers and, in a few cases, may lead to new data centers. Data system approaches would be selected to most efficiently and robustly accomplish the NRC Decadal Study missions. For example, the portion of the Climate Absolute Radiance and Refractivity Observatory (CLARREO) mission to extend the Earth radiation budget satellite data would extend the capabilities of the EOS-developed Clouds and the Earth's Radiant Energy System (CERES) radiation budget data system at the NASA Langley Atmospheric Sciences Data Center. Such an approach takes full advantage of the previous NASA hardware and software development efforts, and ensures a low risk approach to achieving the NRC recommended data sets.

Q3. The decadal survey urges the continuation of the currently operating Terra, Aqua, Aura, and SORCE Earth observation satellites for as long as possible to help minimize data gaps resulting from the loss of NPOESS climate sensors. What is the current plan for continuing these missions and how long are they expected to provide data?

A3. As recommended by the NASA Earth Science Senior Review conducted in April 2007, the Aqua, Terra, and SORCE missions have been approved and budgeted for operation through 2011. The Aura mission is still in its primary mission phase, which will end in 2010. All four of these missions will be examined for further extension in the next Earth Science Senior Review, to be conducted during 2009.

The Earth Science Division within the Science Mission Directorate reviews the status and performance of all of NASA's Earth observing missions operating beyond their primary mission every two years as part of our Senior Review process. The review process considers the satellite performance and instrument health, the value of the observations to NASA research objectives, as well as to all National operational agencies such as NOAA, the Department of Defense and the U.S. Geological Survey, among others. Terra, Aqua and SORCE were included in the most recent review, completed in April 2007. Aura was not included in the 2007 review because that mission is still in its primary mission phase, which will end in 2010. Aura will be included in the next review, to be held in 2009. The Senior Review found that the satellites and their payloads were operating well with no life-limiting factors expected to become important through 2011. The measurements from all four missions were found to have continuing value both for NASA science and for interagency and national objectives.

In general, mission and instrument lifetimes depend on many factors, from individual instrument performance to spacecraft performance. Records show that not many NASA satellites built to typical mission standards operate longer than 10 years in orbit. However, these four satellites have operated in-orbit for less than 10 years, the oldest being Terra at 8 years in orbit. The primary life-limiting factor for these satellites is the available fuel for orbit adjustment maneuvers, and there is sufficient fuel for Terra, Aqua, Aura, and SORCE to support lifetimes to at least 2011.

Q4. According to a report of the MODIS Science Team," as documented in the The Earth Observer *publication, "The use of MODIS data for land studies has exceeded even our most optimistic expectations and has been an unprecedented success for NASA's terrestrial program." Will follow-on sensors to MODIS have the capability to support the growing number of applications derived from MODIS data?*

A4. The planned follow-on sensors to MODIS are the Visible-Infrared Imager Radiometer Suite (VIIRS) instruments on the NPOESS platforms. The VIIRS instruments should have the capability to support most of the land applications pioneered by the MODIS data. The one exception to this is in the area of active fires. VIIRS has some active fire capability, but the current design of VIIRS instrument precludes getting active fire data of MODIS quality.

Q5. In order to understand the science of global climate change, it is necessary to constrain the uncertainty in changes in the temperature of the sun. Unfortunately, the historical record of measurements of total solar irradiance has several unexplained offsets between data sets from different satellites, which are thought to be due to inconsistent sensor calibration (see, for example, http://www.ngdc.noaaa.gov/stp/SOLAR/IRRADIANCE/irrad.html*).*

Q5a. Does NASA agree that sensor calibration is the culprit in these offsets? If so, why did NASA not consistently calibrate sensors on previous solar-monitoring missions? If not, what does NASA identify as the cause of these offsets?

A5a. Sensor calibration is the only possible cause of these offsets; these instruments are monitoring the same Sun at the same time, so should provide the same measurement result. No facility has ever existed to calibrate these total solar irradiance sensors to the desired accuracy levels, although NASA's Glory program is currently funding the establishment of such a facility. Fortunately, measurement continuity combined with instrument stability has allowed tracking of solar variability over this 30-year climate data record despite these offsets, the magnitude of which is time-independent, even in the presence of shorter-term variability in the sun's output.

Q5b. How will NASA ensure that the solar irradiance sensors to be flown on Glory and any future missions will be accurately calibrated and will stay calibrated, so that the data they collect on total solar irradiance will be scientifically useful for climate change analysis?

A5b. Despite the instrument offsets, the existing total solar irradiance (TSI) record is already scientifically useful for climate change analysis because of data continuity and good instrument stability. The Glory mission and future missions are intended to maintain such data continuity with on-orbit tracking of instrument stability. The Glory mission and future missions will also improve instrument accuracy via improved sensor calibrations and end-to-end testing by the new TSI Radiometer Facility planned as part of the Glory program.

Q5c. What is the current technical uncertainty on long-term changes in total solar irradiation? How will Glory and other future solar-monitoring missions change this uncertainty?

A5c. The current technical uncertainty on long-term changes in solar radiation is limited by instability of some of the early instruments. These limit the current technical uncertainty to about 0.004 percent per year from the data record going back to 1978. Since the early 1990s, instruments are more stable, with on-orbit tracking providing 0.001 percent per year uncertainty.

The Glory mission and other future solar-monitoring missions, as well as some currently operating missions such as SORCE, improve this uncertainty with better instrument stability. Improved accuracy on Glory and the new calibration facility, which will provide a baseline against which future instruments should be compared, will maintain a connection to the existing irradiance record across potential data gaps. Improved absolute accuracy with Glory will also better allow detection of solar changes over an extended time period by establishing current-day benchmark irradiance measurements.

Questions submitted by Chairman Mark Udall

Q1. What specifically will NASA do to maintain the Total Solar Irradiance Sensor (TSIS) instrument team for the remainder of Fiscal Year 2007 and through 2008?

A1. The TSIS performs two basic measurements: total solar irradiance using the Total Irradiance Monitor (TIM) and solar spectral irradiance using the Spectral Irradiance Monitor (SIM). These measurements are fundamental to discriminating and quantifying natural versus anthropogenic contributions to climate change. In January 2007, NASA and NOAA delivered a joint report to the Office of Science and Technology Policy (OSTP) addressing the impacts of the NPOESS Nunn-McCurdy Certification on climate measurement goals. In this report, NASA and NOAA determined that continuing the TSIS measurements had the highest priority. The TSIS instrument is built by the Laboratory for Atmospheric and Space Physics (LASP) of the University of Colorado in Boulder, Colorado.

Continuous measurement of the total solar irradiance dates back to the Earth Radiation Budget instrument launched on the NASA Nimbus-7 mission in 1978 and the measurement of the solar spectral irradiance dates back to the SIM instrument on the NASA Solar Radiation and Climate Experiment (SORCE) mission launched in 2003. The SORCE mission presently provides both measurements. The measurement of the total solar irradiance will be continued by the TIM on the NASA Glory mission to be launched late in 2008.

NASA presently supports the TSIS instrument team through the SORCE and Glory missions. These funds are as follows in millions of real-year dollars.

	FY07	FY08
SORCE Operations & TSIS Support:	4.8	3.8
Glory mission LASP Support:	5.3	2.7

Following the NPOESS Nunn-McCurdy Certification decision in June 2006 that de-manifested the TSIS instrument, NASA and NOAA have worked together to identify various options for retaining total and spectrally resolved solar irradiance and other important measurement capabilities de-manifested from NPOESS. Options are presently under consideration by NASA and NOAA, through a process being led by the OSTP.

Q2. Your testimony notes that NASA's response to Sections 313 and 314 of the NASA Authorization Act of 2005 *has been to incorporate the requirements of the Act into NASA's recent research grant solicitation. Could you please describe how*

NASA's applications grants program, which focuses on projects that are "national in scope," responds to the intent of the Act?

A2. NASA's applications grants program, known as the Earth Science Division Applied Sciences Program, recognizes that environmental decision-making, resource management, and disaster response most often resides at the regional, State, local and tribal agency levels—it is imperative that the program work at these levels if it is to have impact. The need to work at all levels of government—and across a broad range of application areas—presents a challenge to the Applied Sciences Program, which is a small program that is managed out of NASA Headquarters in Washington, DC. NASA is addressing this challenge in a number of ways outlined below.

First, in order to maximize NASA's impact (and in keeping with our federal role), the Agency supports projects that are national in scope; that is to say, projects are required to be applicable beyond a one-time application in a single locality. By doing this, NASA is serving a state or locale through the development and demonstration of an Agency capability and at the same time, NASA is laying the groundwork for making that capability available at a national level. In addition, NASA has many projects that only involve federal partners, but will have an impact in all 50 states. For example, NASA is working with the Federal Aviation Administration (FAA) and the National Oceanic and Atmospheric Administration (NOAA) to improve weather prediction for airplane travel.

Second, since NASA does not have direct connections to decision-makers and operational agencies at the State, local, and tribal levels, the Agency uses all available avenues to reach them. Many of our federal partners, such as Environmental Protection Agency (EPA), U.S. Department of Agriculture, and the Department of the Interior (DOI), provide direct access to their regional and state branches, who are directly involved in decision-making at those levels. In addition, we utilize both NASA centers and universities through our competitive solicitations to make connections in their localities. NASA also makes linkages through regional governmental organizations, such as the Gulf of Mexico Alliance and the Western Governors Association—these provide an excellent mechanism for reaching potential end-users and for understanding the needs of a region.

Finally, NASA participates in national organizations of State government officials, such as National States Geographic Information Council (NSGIC), to facilitate matching their needs and federal capabilities.

Q2a. How many remote sensing pilot projects that specifically address State, local, regional, and tribal agency needs has NASA's grants program supported?

A2a. The NASA Earth Science Division Applied Sciences Program currently sponsors 83 competitively selected projects that are in various stages of maturity, nearly all of which extend NASA research capabilities to help decision-makers serve citizens at the local, State and regional levels. Of these 83 active solicited projects, 27 are working *directly* with local/State authorities in 25 different states to solve their problems. This number is expected to increase with the projects that will be selected under the "Decisions 2007 under ROSES" open solicitation. A copy of this solicitation can be found at: (*http://nspires.nasaprs.com/external/viewrepositorydocument/77336/A.20%20Decision%20Support.pdf*).

Specific language from Section 313 of the *NASA Authorization Act of 2005* (P.L. 109–155) was used in the ROSES solicitation to guide the investigators, partners, and peer reviewers on the priorities of the program.

Q2b. Have any workshops presenting the results of pilot projects been held?

A2b. All of Earth Science Division Applied Sciences Program's competitively selected projects are required by contract to formally report their results at the completion of their period of performance. In addition, dissemination of both results and lessons learned through workshops, professional meetings, and other venues is very important for the success of our projects and our program. NASA has found that a practical and effective way to disseminate information on results and lessons learned is through topical workshops that are organized by the Applied Science Program and where all of the appropriate Applied Science projects meet with stakeholders and potential partners to both assess their needs and to disseminate project results and lessons learned. This past year we have conducted workshops on applications topics including Air Quality, Fisheries, Public Health, Disaster Management, and Ecosystems Management.

NASA requires that all Applied Science Program projects plan to participate in workshops for this purpose. For example, NASA included the following language in the 2007 Solicitation, "Decision Support through Earth Science Research Results":

Workshop

The project should plan to travel and participate in a Program-sponsored results conference to disseminate the lessons learned from the project as widely as feasible. The Applied Sciences Program will coordinate this activity with project team during the course of the project; however, the project should budget accordingly to attend this event.

In addition to conducting workshops at the project and program levels, Applied Sciences program managers and grantees attend regional, State, and professional society workshops and participate in interagency working groups such as the Gulf of Mexico Alliance, Commercial Remote Sensing Space Policy Senior Management Oversight Committee, and the Subcommittee on Disaster Reduction.

Q2c. Has the specific advisory group called out in Sec. 314 been established? If not, why not?

A2c. NASA is investigating establishment of an Advisory Group that will report up through the NASA Earth Science Advisory Committee, which is part of the formal NASA Advisory Committee (NAC). NASA expects that the Applied Sciences advisory group, pursuant to Section 314, will be established by the end of this calendar year.

In the meantime, NASA has been seeking external advice on the program through National Academies of Science (NAS) Space Studies Board. A review, entitled "Review of NASA's Earth Science Enterprise Applications Program Plan (2002)," was completed in 2002. This was followed by a second review, entitled "Extending Observations and Research Results to Practical Applications: A Review of NASA's Approach, which has been underway since the fall of 2005." The NAS has indicted that this report will be published before the end of September 2007.

Q3. Your testimony notes that NASA will "preserve and expand the preeminent research and analysis, applied sciences, technology development and educational programs that distinguish the NASA Earth Science endeavor." In specific terms, how do you plan to expand the programs, given your five-year budget profile, and when?

A3. The recently released draft of the National Research Council's Decadal Survey for Earth Science will become the basic guide to future activities as described in the NASA testimony. NASA intends to follow the recommendations of the Decadal Survey to the extent that the available budget will permit. In this process, the Agency's primary objective is to implement the most useful science that we can accomplish within the framework of our existing programs. Expansion will be pursued only where it is driven by the highest quality science and consistent with the available budget.

Q4. You testified, "the Earth Science Subcommittee of the NASA Advisory Council annually examines the split of activities and assesses our scientific performance." When was the last Earth Science Subcommittee assessment of the Earth Science Division's performance and could you, please provide a copy of that assessment for the record?

A4. The NASA Administrator established the Earth Science Subcommittee in early 2006 with the following terms of reference: "The Earth Science Subcommittee (ESS) is a standing subcommittee of the NASA Advisory Council (NAC); it also supports the advisory needs of the Science Mission Directorate (SMD). The scope of the Subcommittee includes the advancement of scientific knowledge of the Earth system through space-based observation and the pioneering use of these observations including process studies, data assimilation and modeling to ultimately enable improved prediction of climate variability and change, weather and natural hazards. In addition to scientific research, the scope encompasses the development of enabling technologies, systems, computing and information management capabilities, including those with the potential to improve future operational systems."

The ESS has met five times since its establishment. The times and main topics on the ESS discussion are summarized below. The agenda and reports to the NAC from the June 2007 are provided for the record. Records of previous subcommittee meetings, including summaries of findings and minutes, are publicly available at: *http://science.hq.nasa.gov/strategy/NAC_sci_subcom/index.html.*

1. *May 3–4, 2006*—ESS discussion and recommendation on allocation of resources within ESD and assessment of balance. Also, ESS discussion on ESD roadmapping.
2. *July 6–7, 2006*—ESS review of SMD draft Science Plan.

3. *September 27–28, 2006*—ESS review of ESD Science Plan; review of NPOESS restructuring efforts.
4. *February 27–28, 2007*—ESS review of ESD Decadal Survey early assessment and ESD preparatory mission concept studies; lunar science workshop participation.
5. *June 12–13, 2007*—ESS review of ESD planning for Community workshops relating to the earliest group of the Decadal Survey missions; review and assessment of selected Annual Performance Goals (APG).

Regarding the APG review, the ESS was asked to support the NASA-wide process of developing the FY 2007 Performance and Accountability Report to Congress. The ESS reviewed ESD material relevant to six APGs, one of each science focus areas. The material reviewed constitutes peer-reviewed results of ESD funded research activities. The considered APGs are pertinent to the Research and Analysis Program. [See Attachment A, Earth Science Subcommittee Report.]

Q5. What was the original objective of the Earth System Science Pathfinder (ESSP) program, and how, if at all, has the objective for the program changed?

A5. The ESSP program, within the NASA Earth Explorers Program, was originally intended to provide frequent, flexible opportunities for rapid-development flight missions focused on specific Earth science investigations. ESSP missions were to be focused on:

- Acquiring key additional measurements in response to new scientific understanding, including exploiting scientific discoveries from facility-class missions;
- Proving the concept and scientific utility of new data sets and measurement approaches; and/or,
- Ensuring the continuity of critical measurement time series (i.e., "gap filler" missions for critical data sets).

The ESSP program was intended to:

- Provide frequent, predictable opportunities for training new investigators and ensuring the continued broad involvement of the scientific community in the overall development of ESE satellite projects;
- Encourage direct involvement of university faculty and students in all aspects of ESE flight mission planning and implementation, and expand the base of academic institutions that have the capability (through experienced faculty) to manage satellite-related technical projects; and,
- Foster development of innovative teaming arrangements that optimize the contributions and minimize the costs of industry, university, and government partners. (from the NRC PI-led mission report, "Steps to Facilitate Principal-Investigator-Led Earth Science Missions" of which Dr. Michael Freilich was an author)

ESSP missions are characterized by: Competitive selection; overall mission life cycle cost constraints (generally small-to-medium missions only); PI-led, focused science objectives defined and managed by the Principal Investigator; and, relatively rapid development (although this has not been achieved). The overall goals of the ESSP program have not fundamentally changed.

Q5a. When was the last solicitation for an ESSP mission issued, and what are the plans for the frequency of future solicitations?

A5a. The last NASA Announcement of Opportunity (AO) for ESSP missions was the ESSP–3 AO, released in 2001 (earlier solicitations were released in 1996 and 1998). The Orbiting Carbon Observatory (in development to be launched in late 2008) and Aquarius (in development to be launched in mid-2010 in collaboration with the SAC–D mission of the Argentine Space Agency CONAE) missions were chosen from the ESSP–3 AO solicitation, with Hydros selected for initial development as a backup should one of the two primary missions not be developed successfully. The President's FY 2008 budget request includes funding for a new ESSP mission to be solicited in late 2008, with launch no earlier than 2014.

Q5b. The decadal survey recommends that ESSP missions be replaced with low-cost research and applications missions that "focus on fostering revolutionary innovation and training future leaders of space-based Earth science and applications." What is NASA's response to this recommendation?

A5b. The recommendation to establish a "Venture Class" program to solicit competitive, ultra-low-cost (~$100 to $200 million) missions or instrument flight opportunities annually or bi-annually will be considered along with the other recommendations of the Decadal Survey for Earth Science as part of the NASA FY 2009 budget formulation process. NASA will be guided by the community consensus, high-priority science issues identified by the Decadal Survey, and will design the most efficient program possible to advance the identified science issues and maintain the balanced, broad program called for by the Survey.

Q6. Your testimony indicates that NASA is "planning a comprehensive review of the [applied sciences] program to ensure that is aligned with the NAS Decadal survey recommendations." What will that review entail, who will conduct it, and what is the schedule?

A6. The Applied Sciences Program's new leadership is currently conducting a multi-step review of the entire program, including program structure and management, in light of the recommendations made in the Decadal Survey with respect to applications, as well as the upcoming National Academy of Sciences report that specifically addresses NASA's approach to applications (see the answer to Question 2c). First, an informal review is taking place through program reviews at NASA Headquarters, visits to the NASA field centers (reviews have taken place so far at Ames Research Center, Goddard Space Flight Center, Stennis Space Center, and Langley Research Center), and through presentations of individual projects by investigators. Second, formal peer reviews of selected projects will take place this fall. Third, a formal programmatic review will take place upon formation of the new Applications Advisory Group in early calendar 2008 (also discussed in Question 2c). This formal review will include both the current program and proposed future strategic direction that the program is considering.

Q7. When will NASA deliver the NASA–NOAA Research to Operations Joint Working Group report, as directed in Section 306 of the NASA Authorization Act, *to Congress?*

A7. The report required pursuant to Section 306 of the *NASA Authorization Act of 2005* (P.L. 109–155) was delivered to the relevant Committees on July 10, 2007.

Q8. You testified that NASA is "letting four contracts for LDCM and they are in the process of being advertised right now and the interaction between them and the technical addition of TSIS will govern our schedule and our decisions."

Q8a. Does the original accommodation study awards issued to the four contractors require them to address the potential accommodation of TSIS and any other sensors (other than OLI)? If not, was a change to the contract made to address those issues?

A8a. The original accommodation study awards issued to the four spacecraft contractors within the Landsat Data Continuity Mission (LDCM) project include options to study interfacing other sensors, in addition to the Operational Land Imager (OLI), to the LDCM observatory. These study options have been initiated and all four spacecraft contractors are in the process of analyzing the manifest of the TSIS on the LDCM.

Q9. What are the technical differences between the requirements issued for the Operational Land Imager (OLI) instrument for the Landsat Data Continuity Mission (LDCM) and the capabilities of the Enhanced Thematic Mapper on the Landsat 7 spacecraft?

A9. The differences between capabilities of the Enhanced Thematic Mapper (ETM) on the Landsat 7 and the requirements for the LDCM–OLI include the following enhancements for OLI: an additional band for coastal zone science; an additional band for cloud detection; and, an enhancement to a band to make images clearer. Thermal imaging capability is not part of the OLI baseline capability. Thermal capability has been investigated as an optional separate instrument that would operate concurrently with the OLI. Following extensive analysis and assessment of alternatives for thermal image data capability, NASA has determined that the current budget profile cannot support the acquisition of the thermal capability for LDCM.

Q9a. Did the RFP for the OLI include the option of including thermal imaging bands?

A9a. No. The thermal capability was scoped as a separate optional instrument.

Q9b. Is NASA analyzing alternatives to LDCM for acquiring thermal imaging data such as instrument flight on other platforms, data purchases, or access to data *obtained from any international satellites that could provide comparable thermal imaging data?*

A9b. The required performance for the Landsat thermal data is not immediately available in proven form from any current source. NASA is assessing international collaboration to potentially provide the thermal capability.

Q10. What plans does NASA have to ensure that scientists would have information on instrumentation details, engineering data, and the like to ensure that data provided from international instruments are of research quality?

A10. NASA has supported the U.S. Geological Survey (USGS) in the definition of a range of Landsat performance specifications that define LDCM performance (spectral bands, radiometry, spatial resolution, geographic registration, and geographic coverage) and a lower end baseline specification. Data meeting the Baseline Specification would replace (in quantity and quality) only a portion of the Landsat data stream should Landsat fail, but such data may also be useful as an ongoing augmentation of the Landsat Data Continuity Mission (LDCM), currently projected to launch sometime in 2011. Acquired data must be characterized and verified against these specifications to ensure data quality and continuity. NASA will support USGS to ensure that acquired data is characterized and verified.

NASA has a rich history of working with international partners on joint mission development, and on instrument data exchange and availability for U.S. scientists' research and educational use. NASA makes such data products supplied from an international partner available under terms and conditions required by the appropriate Memorandum of Understanding (MOU). Where data are available through NASA data systems, instrumentation details, engineering data, and documentation on data accuracy are also available and supplied with the data. NASA works through the Committee on Earth Observation Satellites (CEOS) to promote more generally agreement and implementation of standards both for instrument data documentation availability, and for instrument calibration and validation procedures. CEOS membership encompasses the world's government agencies responsible for civil Earth Observation (EO) satellite programs, along with agencies that receive and process data acquired remotely from space. Within CEOS working groups, international projects are voluntarily undertaken for coordination of resources for data availability, and for inter-calibration of like instruments using in situ instrumentation by the appropriate space agencies.

Questions submitted by Representative Tom Feeney

Q1. In his statement, Dr. Anthes asserted that "we are faced with an Earth observation program that will dramatically diminish in capability over the next 10–15 years. . . Between now and the end of the decade, the number of operating missions will decrease dramatically, and the number of operating sensors and instruments on NASA spacecraft. . .will decrease by some 35 percent, with a 50 percent reduction by 2015." Do you agree with this assessment?

A1. NASA is presently operating an impressive set of 14 Earth-observing spacecraft carrying over 50 instruments. In addition, the President's FY 2008 budget request includes funding for an additional seven identified Earth observing missions to launch between 2008 and 2014, and funding for a small to medium Earth System Science Pathfinder (ESSP) mission, which will be solicited for competitive selection late in FY 2008 with flight in the 2014–2015 timeframe. The National Research Council (NRC) Earth Science Decadal Survey identifies 15 new missions to address key Earth system science research issues over the next 10 to 15 years.

While 11 of NASA's 14 currently operating missions are indeed beyond their baseline lifetime, they continue to operate well and to provide high quality measurements for the research and operational communities. From February to April 2007, NASA's Earth Science Division conducted the biennial "Senior Review" to examine Earth observing missions operating beyond their baseline mission. After careful technical analysis, both the operations and science panels in the Senior Review concluded that all 11 of the operating missions were returning valuable data and were not suffering from imminent mission-threatening technical problems. Consequently, the Senior Review recommended that NASA continue to fund operations and science analyses for all of these missions for at least two more years.

The President's FY 2008 budget request contains funding for the development and launch of seven new Earth observing missions between 2008 and 2014:

- OSTM (Ocean Surface Topography Mission; June 2008 launch) to continue the time series of precision global ocean sea level measurements initiated by TOPEX/Poseidon in 1992 and presently obtained by JASON–1;
- OCO (Orbiting Carbon Observatory; December 2008 launch) to initiate global measurements of atmospheric carbon dioxide and to identify, for the first time, regional (1000 km spatial scale) sources and sinks of CO_2;
- Glory (December 2008 to March 2009 launch) to continue the 26-year consistent time series of solar irradiance measurements and to initiate global measurements of atmospheric aerosol concentration and scattering properties;
- Aquarius (July 2009 launch) to make first-ever, global measurements of ocean surface salinity;
- NPP (NPOESS Preparatory Program; September 2009 launch) to continue the time series of key EOS sensor measurements, and to provide risk-reduction for the tri-agency NPOESS operational satellite system;
- LDCM (Landsat Data Continuity Mission; July 2011 launch) to continue the 30-year long record of moderate-resolution land imaging; and,
- GPM (Global Precipitation Measurement Mission; June 2013 and June 2014 launches) to extend to the entire globe the present measurements of tropical precipitation from the presently operating Tropical Rainfall Mapping Mission (TRMM), allowing accurate, global rainfall measurements every three hours.

In addition to these seven missions comprising eight launches between 2008 and 2014, the FY 2008 budget request also includes funding for a small to medium Earth System Science Pathfinder (ESSP) mission, which will be solicited for competitive selection late in FY 2008 with flight in the 2014–2015 timeframe.

The NRC Earth Science Decadal Survey, which was released just three weeks prior to the FY 2008 budget submission, identifies 15 additional Earth observing missions for NASA in the 2010–2022 timeframe.

Q2. What are your views regarding the mission cost estimates included in the Earth Sciences Decadal Survey? Are they credible?

A2. NASA's Earth Science Division conducted detailed Center-based technical and cost "concept studies" for each of the missions identified for NASA in the Decadal Survey. These studies identified technical challenges and developed cost estimates which include realistic launch service costs and the mission operations and science analysis costs associated with each mission. The results of each of these studies are being confirmed with independent cost estimates.

In cases where mission designs are well established, technological risks are low, and significant previous NASA investment has been made to understand the missions, mission cost estimates in the Decadal Survey are relatively close to the cost estimates of ongoing NASA mission concept studies. In other cases, the preliminary studies suggest substantial differences between the detailed NASA studies and the estimates developed by the NRC.

Q3. The Decadal Survey highlighted the importance of developing a strategy to transition technologies from NASA to operational systems. How is transition managed today? What steps can NASA take to improve technology transition between researchers and the applications community?

A3. Transition of satellite measurement capability from research to operations has been, and remains, challenging. NASA developed and demonstrated several of the instruments and measurement concepts that form the foundation for the present National Oceanic and Atmospheric Administration (NOAA) and Department of Defense (DOD) operational weather satellite systems, such as the Advanced Very High Resolution Radiometer (AVHRR) and the Special Sensor Microwave Imager (SSM/I) multi-channel microwave radiometer flown on the DOD Defense Meteorological Satellite Program. Joint work between NASA and NOAA has resulted in processes that allow near-real-time measurements from the research missions to be merged with data from NOAA operational satellites that result in enhanced operational weather predictions (e.g., QuikSCAT; TRMM; AIRS; MODIS fire products; JASON–1). Other instruments that have transitioned from research to operations include the Solar X–Ray Imager which currently flies on NOAA Geostationary Operational Environmental Satellites. Work is ongoing to transition an on-orbit lightning capability onto NOAA's next generation GOES–R series.

Following recommendations from National Research Council reports (e.g., the 2003 report of the Committee on NASA–NOAA Transition from Research to Operations) and the *NASA Authorization Act of 2005* (P.L. 109–155), a NASA–NOAA Joint Working group has been re-established and has addressed a wide range of issues associated with research-to-operations transitions. NOAA and NASA are also discussing approaches to initiating joint NASA–NOAA program(s) focused on developing new instruments for operational services. Other focused groups such as the NOAA–NASA–DOD Altimeter Working Group meet bimonthly to coordinate research, civil, and defense operational measurement systems to acquire global sea-level height and wave condition measurements.

The NASA Applied Science Program is focused specifically on working with applications mission agencies (such as the Federal Aviation Administration, Department of Homeland Security, Environmental Protection Agency, etc.). In this way, the Applied Science Program efficiently transitions the knowledge gained through NASA Earth science missions and the research and analysis program, into information directly useful to other mission agencies with national or super-regional scope.

Q4. To what degree are the governments of large developing countries, such as China and India, taking an interest in climate change research and attempting to mitigate further damage to the environment? Do they acknowledge that climate change may be, in part, a consequence of human activity? Has a credible estimate been developed on the amounts of some pollutants ' released into the atmosphere by these countries?

A4. Perhaps the best indicator of the interest taken by the governments of large developing countries, such as China, India, and Brazil, in the issue of climate change and associated research is the very active role they play in the Intergovernmental Panel on Climate Change (IPCC), the leading international forum on this issue. Based on reported discussions at recent IPCC meetings, it is clear that these nations acknowledge a connection between human greenhouse gas emissions and climate change. However, they also reportedly seek the acknowledgement from developed nations that those nations that industrialized first shoulder a greater responsibility for the current atmospheric greenhouse gas levels than do nations which industrialized later. These nations are also reportedly concerned about the cost of reducing greenhouse gas emissions to developing economies. Another indicator of the interest taken by the Indian government in this area is the bilateral Climate Change Partnership between the United States and Indian governments. Formed in 2002, this partnership provides a forum for both nations to engage in domestic and international efforts to address the issue of Climate Change, including looking at new technologies and policies aimed at reducing greenhouse gas emissions. With regard to assessing the release of pollutants into the atmosphere, NASA's Earth-observing missions and NASA-funded research studies are providing unique, quantitative, global measurements of atmospheric constituents which play key roles in determining air quality as well as influencing climate change. While many space-based global measurement sets have not, to date, provided the high-resolution and frequent measurements required for determining the compositions and magnitudes of sub-regional pollution sources, advanced analyses applied to recent measurements from the NASA Aura mission have provided first-ever quantitative data on pollutant levels at regional and national scales. For example, sophisticated NASA-developed algorithms allow accurate global measurements of column sulfur dioxide (a key industrial pollutant generated from smelters and electrical generation plants and the source of "acid rain") on scales of thousands of kilometers, from the Ozone Measuring Instrument on the Aura mission. These measurements show that in 2005, Chinese factories emitted 2.5 million tons of sulfur dioxide into the atmosphere, an increase of more than 27 percent over the estimated Chinese emission levels in 2000. The Orbiting Carbon Observatory, to be launched by NASA in late 2008, will provide first-ever global measurements of atmospheric carbon dioxide sources and sinks on scales as small as 1000 km (628 miles). NASA's role is to advance Earth System science through Earth observing research satellite missions, and vigorous analysis and modeling efforts to elucidate key Earth system processes and the interactions between them. While these measurements form the foundation for many scientific and policy analyses, NASA itself does not conduct policy studies.

Attachment A:

Earth Science Subcommittee Report
June 12–13, 2007 Meeting
NASA Headquarters

From: The NASA Earth Science Subcommittee - Daniel J. Jacob (Chair, *djacob@fas.harvard.edu*), Roni Avissar, John R. Christy, Lisa Curran, Jonathan Foley, James Hansen, Gregory Jenkins, John Jensen, Patricia Matrai, Julian McCreary, Jean-Bernard Minster, Michael Ramsey, Kamal Sarabandi, Mark Simons, Konrad Steffen, Edward Zipser

To: Edward David, Jr. (Chair, NAC Science Committee)

Cc: Greg Williams (NAC Science Committee Executive Secretary), Michael Freilich (ESD Director), Bryant Cramer (ESD Deputy Director), Jack Kaye (ESD Associate Director for Research), Theodore Hammer (ESD Associate Director for Flight Program), Teresa Fryberger (Associate Director for Applied Sciences), Lucia Tsaoussi (ESS Executive Secretary)

Date: June 28, 2007

Dear Dr. David:

The Earth Science Subcommittee (ESS) met on June 12–13, 2007 at NASA Headquarters. We received updates on ESD (Michael Freilich) and NPOESS (Bryant Cramer), and briefings on (1) the sub-orbital program (Andy Roberts), (2) the technology program (Amy Walton), and (3) the upcoming community workshops aimed at defining the first wave of satellite missions from the NRC Decadal Survey. We reviewed and graded the FY 2007 Earth Science Performance and Accountability Report, and discussed the Lunar Science Workshop Report as well as the response of the NAC to our March 2007 recommendation for an Earth Science Initiative.

The central recommendation from our March 2007 letter to the NAC was for an Earth Science Initiative to enable ESD to implement the program of missions designed by the NRC Decadal Survey (DS) and which we fully endorsed. We pointed out that the bleak long-term outlook for ESD funding does not allow for implementation of the DS and recommended that resources for an Earth Science Initiative be found, either within or outside NASA, in order to implement the DS—corresponding to a 30 percent increase of ESD budgets, i.e., a return to 2000 funding levels. We were disappointed that the NAC decided not to forward the recommendation to the Administrator, despite the support from the NAC Science Committee, on the grounds that requesting new funding was outside the charter of the NAC. But this apparent technicality leaves unsolved the problem of how NASA is to respond to the DS. At a time of great public concern over global change, NASA cannot just bury its head in the sand.

The DS calls for 14 strategic missions (typically in the ~$500M range) to be launched over the 2010–2020 period. It also calls for a new class of Venture missions in the $100–200M range to foster the development of new ideas. The ESD budget outlook going out to 2014 offers opportunities for just two strategic missions, and has no line for Venture missions. ESS scrutinized the ESD budget and received briefings on all its major components. We do not see how the current budget could be reconfigured to enable more effective implementation of the DS. The hard truth is that the 30 percent budget cut that ESD has suffered since 2000 incapacitates it from developing new initiatives. The DS indicates that its slate of 14 missions would be fully doable if ESD funding were restored to 2000 levels. Implementation of the DS requires new resources from an Earth Science Initiative to start in FY09 at the latest.

We are concerned that NASA may feel that it has properly responded to the DS if it launches say the first wave of four DS missions over the next decade. In fact, the ensemble of 14 missions for the next decade put forth by the DS represents a carefully crafted synergistic ensemble, and the DS specifically warns against piecemeal selection of missions. The DS Executive Summary states: *"In the event of budget shortfalls, re-evaluate the entire set of missions given an assessment of the current state of international global Earth observations, plans, needs, and opportunities. Seek advice from the broad community of Earth scientists and modify the long-term strategy rather than dealing with one mission at a time."* We will face this situation in FY09 unless an Earth Science Initiative is implemented. We remain hopeful that resources for such an Initiative will be found, either through the Congressional allocation of FY08 or through the Administrator's request in FY09.

We ask the NAC to advise the Administrator that in the absence of an Earth Science Initiative in place by FY09 to implement the NRC Decadal Survey, NASA will have defaulted on its implementation of the DS and will need to re-think its whole Earth science strategy with input from the broad scientific community. This would represent a major failure and we remain hopeful that positive action will be taken over the next year.

The current NPOESS debacle has further heightened the crisis for Earth observation from space. The NPOESS climate sensors TSIS, APS, OMPS–Limn, ERBS, and ALT were de-manifested as part of the recent Nunn-McCurdy Certification. CMIS was partly maintained but with reduced capability—if it loses its capability to measure microwave surface temperatures (that was not clear to us), then it will be of little use as a climate sensor. A positive development is that OSTP tasked NASA and NOAA to examine options for recovering the ensemble of NPOESS climate measurements through other means. As we have stated in previous letters, long-term, continuous, well-calibrated measurements of key climate variables from space are critical for monitoring climate variability and change and for testing our understanding of the same. ESD shared with us four options presently under consideration in their joint discussions with NOAA. Options 1 and 4 involve restoration of the climate sensors on later NPOESS satellites, while options 2 and 3 abandon the association with NPOESS and instead rely on "climate free-flier" satellites to carry the climate sensors. Options 2 and 3 seem to us the best choices cost-wise and to avoid being hostage to the NPOESS program. **We recommend that long-term monitoring of climate variables from space be conducted from "climate free-fliers" (options 2 and 3 of the NASA/NOAA White Paper) for reasons of both reliability and cost.**

ESD will hold community workshops over the next month to better define each of the four notional missions representing the first wave (2010–2015) of DS missions (CLARREO, SMAP, ICESat-II, DESDynI). The workshop chairs briefed us on their plans. We were impressed by their dedication and by the dynamic that these workshops represent for implementing the DS. We have two major comments for their consideration.

(1) The CLARREO presentation implied that CLARREO should be considered as a sustained measurement, but this would have cost implications beyond those estimated by the DS. **An important decision to be made at the CLARREO workshop is whether or not the mission entails a long-term commitment to spectrally resolved thermal IR measurements, as this will greatly affect the cost of the mission. If long-term commitment is required, there should be a strategy for transition from research to operations that will enable projection of the long-term impacts on ESD budgets.**

(2) Consideration should be given to different configurations of the DESDynI and ICESat-II sensors. The DS combined the surface deformation InSAR and vegetation structure laser altimeter into one notional mission (DESDynI), but called also for further analysis of whether this combination was viable and whether a better combination might be achieved with the ICESat-II laser altimeter. There will be differences in the optimal orbits for each of these instruments, but is it possible to settle for a less-than-optimal orbit in order to enable joint launch at considerably lower cost? These issues should be addressed at the DESDynI and ICE–Sat-II workshops. **We recommend that ESD keep an open perspective on the opportunities for different configurations of the L-band InSAR, the vegetation laser altimeter, and the ice surface altimeter onto common satellite platforms for purposes of cost reductions. We encourage cross-participation in the ICESat-II and DESDynI community workshops.**

We reviewed the outcomes of the February Lunar Science Workshop and in particular the recommendations for Earth Science. We were pleased to see a strong statement in the workshop report that recommendations for missions enabled by the lunar architecture must be vetted through a NRC Decadal Survey or similar process. We were pleased to see a strong affirmation of the value of Earth science observations from the Moon. As noted in the report, the current proposed site for the polar base is an issue because of its limited view of the Earth, and an outpost at Mt. Malapert with much better Earth viewing capability would address this issue. **We wish to emphasize that satellites at the Earth-Moon L1 point supporting lunar operations would also represent ideal platforms for observing the Earth.**

We received a briefing on the ESD sub-orbital program from manager Andy Roberts. We had expressed concern in the past that this important program was lacking direction. We were pleased to see a strong articulation of the main purposes of the sub-orbital program within ESD: (1) satellite cal/val including science-directed, (2) new sensor development, (3) process studies. We were pleased to see the value of the UAS (Unmanned Airborne Systems) expressed in terms of their scientific purpose (endurance, extended low-altitude flight) instead of abstract and likely unaffordable technological goals. We were impressed by the educational vision of the sub-orbital program, recognizing aircraft missions as a unique means to provide students with hands-on experience and train future leaders. We remain concerned that the core aircraft (both manned and UAS) are under-utilized and that this represents a substantial cost burden to the program. Hopes from cost-sharing by non-NASA customers have not materialized. **We recommend that the sub-orbital program take a hard look at its needs for core aircraft to determine whether significant cost savings could be achieved at minimal loss for science by decommissioning one of the aircraft.**

We were impressed by the briefing on the ESD technology program from manager Amy Walton. The program has a clear focus and balance, including in particular the development of cross-cutting and targeted technologies aimed at implementing the DS. A concern expressed by Walton was how to support the development of targeted technologies (directed at one specific mission) without creating a non-competitive pipeline for subsequent selection of the mission. **We recommend that at least two competing approaches or groups be supported in the development of any targeted technology in order to maintain competition at the subsequent level of mission selection.**

We were asked to review and grade the ESD FY07 Performance and Accountability Report, but we were not satisfied by the process under which we were asked to carry out the review. The performance report submitted to us was very uneven across areas. We would, for example, have liked to see for each area *i)* the number of scientists actively carrying out research, *ii)* a list of publications, *iii)* perhaps abstracts of selected publications, and *iv)* some synthesis paragraphs that provide an overview of activities, accomplishments, and hindrances. We were not clearly told what readership was targeted by the report. Our own charge was not clear—simply rate each outcome as green, yellow or red? Provide critical comments on the supporting text? **We ask that the procedure for reviewing the ESD Performance Evaluation and Accountability Report be improved next year, and that the material submitted to ESS for review be more informative.**

We include as Appendices for specific action by the NAC our recommendations that (1) the Administrator be advised that NASA will default on its response to the DS and have to rethink its Earth Science Program if funding for an Earth Science Initiative does not materialize by FY 2007; (2) climate free-flyer satellites be used in lieu of NPOESS for long-term monitoring of key climate variables, (3) the Earth-Moon L1 point be recognized as the optimum platform for observing the Earth from the Moon as part of the Lunar Exploration Architecture. Our other recommendations may be best considered at the level of the ESD leadership.

Sincerely,

The Earth Science Subcommittee

APPENDIX 1:

Proposed Recommendation for the NAC Science Committee

Subcommittee Name: Earth Science

Chair: Daniel J. Jacob

Date of Public Deliberation: June 12–13, 2007

Date of Transmission: June 28, 2007

Short Title of Proposed Recommendation: **Action on NASA Earth Science Initiative Needed by FY09**

Short Description of Proposed Recommendation:

We ask the NAC to advise the Administrator that in the absence of an Earth Science Initiative in place by FY09 to implement the NRC Decadal Survey, NASA will have defaulted on its implementation of the DS and will need to re-think its whole Earth science strategy with input from the broad scientific community. This would represent a major failure and we remain hopeful that positive action will be taken over the next year.

Outline of the Major Reasons for Proposing the Recommendation:

The central recommendation from our March 2007 letter to the NAC was for an Earth Science Initiative to enable ESD to implement the program of 14 missions for 2010–2020 designed by the NRC Decadal Survey (DS) and which we fully endorsed. The NAC decided not to forward the recommendation to the Administrator on the grounds that requesting new funding was outside its charter. This technicality leaves unsolved the problem of how NASA is to respond to the DS. At a time of unprecedented public concern over global change, NASA cannot just bury its head in the sand. As explained in our letter, the current ESD budget outlook completely defaults on the DS. Piecemeal implementation of the DS is not an option. Implementation of the DS requires new resources from an Earth Science Initiative to start in FY09 at the latest. In the absence of such an Initiative, NASA will need to totally re-think its long-term strategy for Earth Science.

Outline of the Consequences of No Action on the Proposed Recommendation:

This is best stated by the DS Executive Summary: *"In the event of budget shortfalls, re-evaluate the entire set of missions given an assessment of the current state of international global Earth observations, plans, needs, and opportunities. Seek advice from the broad community of Earth scientists and modify the long-term strategy rather than dealing with one mission at a time."*

APPENDIX 2:

Proposed Recommendation for the NAC Science Committee

Subcommittee Name: Earth Science

Chair: Daniel J. Jacob

Date of Public Deliberation: June 12–13, 2007

Date of Transmission: June 28, 2007

Short Title of Proposed Recommendation: **Free Flier Satellites for Climate Monitoring**

Short Description of Proposed Recommendation:

We recommend that long-term monitoring of climate variables from space be conducted from "climate free-flier" satellites (options 2 and 3 of the NASA/NOAA NPOESS White Paper), rather than through the NPOESS suite, for reasons of both reliability and cost.

Outline of the Major Reasons for Proposing the Recommendation:

The current NPOESS debacle has heightened the crisis for Earth observation from space. The NPOESS climate sensors TSIS, APS, OMPS-Limn, ERBS, and ALT were de-manifested as part of the recent Nunn-McCurdy Certification. CMIS was partly maintained but with reduced capability. OSTP tasked NASA and NOAA to examine options for recovering the ensemble of NPOESS climate measurements through other means. ESD shared with us four options presently under consideration in their joint discussions with NOAA. Options 1 and 4 involve restoration of the climate sensors on later NPOESS satellites, while options 2 and 3 abandon the association with NPOESS and instead rely on "climate free-flier" satellites to carry the climate sensors. Options 2 and 3 are the best choices for reasons of both cost and reliability.

Outline of the Consequences of No Action on the Proposed Recommendation:

As we have stated in previous letters, long-term, continuous, well-calibrated measurements of key climate variables from space are critical for monitoring climate variability and change and for testing our understanding of the same. NPOESS has demonstrated its failure in commitment to climate monitoring. Long-term climate observations should not be held hostage to NPOESS's other priorities. We stand at risk of losing critical continuity in measurements of climate variables.

APPENDIX 3:

Proposed Recommendation for the NAC Science Committee

Subcommittee Name: Earth Science

Chair: Daniel J. Jacob

Date of Public Deliberation: June 12–13, 2007

Date of Transmission: June 28, 2007

Short Title of Proposed Recommendation: **Earth Observation from the Earth-Moon L1 point**

Short Description of Proposed Recommendation:

We ask the Lunar Exploration Architecture to recognize that satellites at the Earth-Moon L1 point supporting lunar operations would also represent excellent platforms for observing the Earth.

Outline of the Major Reasons for Proposing the Recommendation:

The current proposed polar site for the lunar base is not adequate for Earth observation because of its limited view of the Earth. An outpost at Mt. Malapert with much better Earth viewing capability would address this issue, but the best and most cost-effective viewing point would be on lunar operations satellites at the Earth-Moon L1 point.

Outline of the Consequences of No Action on the Proposed Recommendation:

A viewing site on the Earth-facing side of the surface of the Moon would also be adequate for Earth Science but we are concerned about the infrastructure and costs involved, particularly if such a site is not associated with the main lunar base. The Earth Science community has a lot to gain from viewing platforms associated with Lunar Exploration and input from that community should continue to be sought.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Richard A. Anthes, President, University Corporation for Atmospheric Research; Co-Chair, Committee on Earth Science and Applications from Space, National Research Council, The National Academies

Questions submitted by Chairman Bart Gordon

Q1. At the February 13, 2007 hearing of the Committee on Science and Technology on the Earth science decadal survey, Dr. Moore testified that "through focusing on smaller missions and avoiding large, multi-instrumented platforms, a robust strategy for the future of Earth science can be achieved with reasonable investments." Could you please elaborate on the potential for using small missions?

Q1a. What is the advantage of this approach over using large satellites for multiple instruments?

A1a. There is no simple answer to this question; a mixture of a number of small missions with one or just a few instruments (payloads) and a few larger, multi-instrumented platforms is probably optimal. Small missions are usually much simpler than the large missions and hence can be carried out faster, at lower cost, and with less risk. Large satellites carrying multiple payloads can also be efficient by sharing satellite and launch costs. In addition, it is sometimes important to have measurements of different variables made at the same time and place, and this is more easily done with a single large platform carrying multiple instruments.

Small, single instrument missions also require less management oversight and coordination through the integration and test phase of the mission. For multi-instrumented platforms, integrated schedule requirements can become a key driver, where the slowest instrument drives the schedule (and consequently budget). Smaller platforms with fewer instruments, therefore, are less constrained and can maintain a higher level of flexibility and often efficiency. The downside, of course, is a higher relative cost of spacecraft and launch services associated with each instrument needing its own mission.

Questions submitted by Chairman Mark Udall

Q1. The Earth Science Subcommittee of the NASA Advisory Council's Science Committee proposed a NASA Earth Science Initiative. That proposal involves redirecting support for a planned FY08 solicitation for an Earth System Science Pathfinder to a decadal survey mission. What is your reaction to that proposal?

A1. Redirecting the planned FY08 ESSP solicitation to implement a decadal survey mission is consistent with the Committee's recommendations. The requirements for Earth science observations greatly exceed the missions that can be supported with the present NASA Earth science budget, which means there is insufficient funding to support non-targeted proposal opportunities to the extent needed to ensure a robust, innovative total space program. In order to balance the need for new, creative approaches with known national observation needs, the Decadal Survey's approach was to recommend a set of priority science missions *and* concurrently sponsor "Venture class" mission opportunities. As stated in the decadal survey, *"The Venture class of missions, in particular, would replace, and be very different than the current Earth System Science Pathfinder (ESSP) mission line, which increasingly has become a competitive means for implementing NASA strategic missions."* Venture class missions are intended to provide more frequent funding opportunities for lower cost investigations and are not limited to traditional instrument-on-spacecraft missions. As the Decadal Survey suggests, Venture class missions could include stand-alone missions, instruments of opportunity flown on partner spacecraft, or sets of instruments flown on suborbital platforms.

The current Earth System Science Pathfinder (ESSP) program has not provided timely, lower cost missions; moreover, it is difficult to develop a focused technology development program if there is not a clear set of defined missions at low, medium and higher cost levels. Consequently, the Decadal Study recommended replacing the ESSP line with Principal Investigator lead Venture class missions and, most importantly, to establish a clear sequence of well defined missions. A healthy national program requires both the named missions plus regular, lower-cost, and competitively selected Venture class missions.

Q2. Your testimony refers to the importance of ensuring adequate instrument characterization, calibration, and validation in international collaborations on Earth observing missions. Could you please explain why the characterization, calibra-

tion, and validation are important and what type of information is required for those processes?

A2. The *characterization, calibration, and validation,* sometimes called "Cal/Val," of all observing systems are part of a quality assurance process that must be an integral part of any Earth observing mission. All raw observations (e.g., an observed value of radiation from a layer in the atmosphere) have errors—bias and random errors. Converting the raw observations into useful products (e.g., temperature) and/or using them effectively in weather prediction models depend on the algorithms used to do the conversion, or processing. The algorithms themselves may also introduce errors. Without knowing all of these error properties or their characteristics, the observations and derived products are at best useless and at worst highly misleading, contributing misinformation to users. Thus all new instruments or observing systems must be *calibrated* using other independent observations with known accuracies and error characteristics, to make sure the measurements are accurate and unbiased. Most instruments in space need periodic re-calibration as well, since they may "drift" away from the truth. In addition, the process of obtaining the observations themselves and generating the data products derived from them must be *validated,* so that the quality and other characteristics of the observations and products are known.

The calibration process requires comparison of the measurements at different levels of processing (e.g., raw and fully processed data) with a known standard, and then making adjustments to the instrument or the processing algorithms as appropriate to reduce or eliminate any biases or other errors. For example, a new weight scale may need adjustments to read accurately; without this calibration, the scale might read two or three pounds too high or too low, thereby providing misleading information. In another example, a new thermometer must be calibrated so the error and any required corrections are determined (e.g., via calibration constants) so that the thermometer can be adjusted to show the true temperature.

The overall Cal/Val process includes comparing the observations and data products against other observations or analyses, to ensure that they are accurate. Observations of the same variable, such as temperature, from independent instruments and techniques are thus valuable for understanding and documenting the errors associated with the different measurements. Independent observations of the same variable are also very useful in weather prediction models, because they produce a more accurate forecast than a single type of observing system does. The Decadal Survey report discussed the importance of Cal/Val in a number of places.

Q3. What detailed information would scientists require to ensure the data provided by international missions/instruments are of research quality?

A3. Scientists require the raw data and all the information used to process these data; they must know and understand the entire Cal/Val process. Without full knowledge of the characteristics of the raw data and processing techniques, scientists are unable to verify the accuracy and other error properties of the observations and any products derived from them. Deriving full benefit from the observations requires full knowledge of the Cal/Val process. Scientists also need to know details about the instrument and details of its pre-launch characterization to understand instrument performance prior to launch.

Q4. Your testimony refers to the potential lost opportunities for verifying the effectiveness of actions to stabilize greenhouse gases, monitoring the efforts of other countries to reduce greenhouse gases, and ensuring that investments the United States is expected to make in reducing greenhouse gas emissions are working. Could you please elaborate on how the U.S. Earth observing system might be used to validate the effectiveness of U.S. policies, including carbon sequestration, and actions to reduce and mitigate the effects of climate change?

A4. Satellite observations have a great role to play in monitoring what other countries are doing in a variety of environmental areas including atmospheric and ocean pollution; deforestation; and other changes in land characteristics, urbanization, and agricultural practices and yields. In many cases it is impossible to obtain *in situ* observations from other countries because of cost, security, and other issues. Satellites provide the only practical means to observe all countries and their activities including emission of greenhouse gases.

As described in the Decadal Survey report, the upcoming Orbiting Carbon Observatory (OCO) mission will be particularly valuable in validating carbon policy effectiveness. After launch in 2008, the OCO mission will collect precise global measurements of carbon dioxide (CO_2) in the Earth's atmosphere. The global coverage, spatial resolution, and accuracy of OCO measurements will provide a basis to characterize and monitor the geographic distribution of CO_2 *sources* and *sinks* and quantify their variability. Based on these measurements, scientists will map the natural and man-made processes that regulate the exchange of CO_2 between the Earth's surface and the atmosphere on both regional and continental scales.

Understanding today's regional and temporal patterns of CO_2 sources and sinks is necessary for reliable projections of future atmospheric CO_2 concentrations. Direct oceanic and terrestrial measurements of carbon and/or the flux of CO_2 are important, but resource-intensive and hence the observations are sparse and difficult to extrapolate in space and time. Space-based measurements of primary production and biomass are valuable and needed and, consequently, the Decadal Study recommended the DESDynI and HyspIRI missions.

The current set of direct *in situ* atmospheric observations is far too sparse for the determination of CO_2 sources and sinks; however, long-term, accurate measurements from space of atmospheric CO_2 column measurements with global coverage would allow the determination and localization in time and space of CO_2 fluxes both over the ocean and over terrestrial systems. What is needed for space-borne measurements is a highly precise global data set for atmospheric CO_2 column measurements without seasonal, latitudinal, or diurnal bias. This is initially being addressed using existing satellite-based measurements and with the first generation of satellite instruments designed specifically for passive CO_2 measurements, such as the Orbiting Carbon Observatory (OCO) and the Japanese Greenhouse gas Observing Satellite (GOSAT). While these instruments will make a major step forward in our understanding of CO_2 distributions, it is internationally recognized that an active CO_2 mission using a laser is the only way to achieve observations at all seasons and all latitudes, day/night coverage, and under both clear and broken cloud conditions. As a result, the Decadal Study recommended the development of an active, laser-based CO_2 mission, ASCENDS, as the important next step after OCO and GOSAT.

Q5. Is there a consensus (among federal agencies, academia, and other users) on a set of climate and environmental measurements to which the nation should commit for sustained observations? If so, what is the set? If not, should there be such a set of consensus measurements and what would be involved in reaching consensus?

A5. There have been a number of high-quality and intensive studies with recommendations of important climate variables that should be monitored on a continuous basis, but the lists of "essential climate variables" generated by these studies are rather long, sometimes including 20 or more variables. These "essential" observations all contribute to an understanding of the total Earth system, and I support them. My very short list of absolutely essential observations to make on a continuous global basis include solar and Earth radiation, atmospheric and ocean temperature, atmospheric water vapor, ozone, carbon dioxide and sea level height. The Decadal Survey report recommends several missions to obtain these cornerstone climate observations: CLARREO, GPSRO, ASCENDS, SWOT, ACE, and PATH. In addition to supporting climate monitoring and research, several of these observations also make important contributions to weather forecasting and warnings (e.g., atmospheric and ocean temperature, atmospheric water vapor and sea level height).

A recent expert reference containing recommendations for important climate variables may be found in: WMO, 2006: *Systematic Observation Requirements for Satellite-based Products for Climate.* Global Climate Observing System (GCOS)-107 (WMO/TD No. 1338).

Question submitted by Representative Tom Feeney

Q1. The Decadal Survey recommends that the Office of Science and Technology Policy study and assign roles and responsibilities among relevant federal agencies to establish a rational and enduring Earth remote sensing program. Have you briefed OSTP on your report, and if so, how did they react to your recommendation?

A1. Dr. Berrien Moore and I briefed OSTP on January 30, 2007, just after the time of the release of the NRC report, "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond." In addition to a discussion of specific observational needs and missions, we discussed the recommendation specifically to OSTP:

"Recommendation: The Office of Science and Technology Policy, in collaboration with the relevant agencies, and in consultation with the scientific community, should develop and implement a plan for achieving and sustaining global Earth observations. This plan should recognize the complexity of differing agency roles, responsibilities, and capabilities as well as the lessons from implementation of the Landsat, EOS, and NPOESS programs."

. . .as well as the more general recommendation:

"Recommendation: A formal interagency planning and review process should be put into place that focuses on effectively implementing the recommendations made in the present decadal survey report and sustaining and building the knowledge and information system for the next decade and beyond."

In response to these recommendations and a perceived national need, OSTP has initiated, under the auspices of the U.S. Group on Earth Observations (USGEO) [an interagency subcommittee under the National Science and Technology Council], a two-pronged strategy to address national Earth observational needs across agencies.

First, USGEO is developing a national Earth observations policy which builds upon the National Space Policy and other existing policies to clarify roles and responsibilities of federal agencies in the collection, distribution, and preservation of Earth observations data. This policy will include guidance on research-to-operations transitions and international coordination of Earth observations activities.

Second, USGEO is simultaneously pursuing an assessment and planning effort to begin to establish a national framework that includes existing Earth observation capabilities, national Earth observation needs, and a gap analysis. USGEO does not intend to inventory or catalog every observational capability in the country, but will focus on prioritization of the major observational efforts required to address the societal benefits outlined in both the USGEO Strategic Plan and the NRC Decadal Survey report.

Because USGEO is a White House group that involves all the active Federal agencies engaged in Earth observations, we are hopeful that both the policy and the assessment/plan will address these important national needs on an interagency basis.

Q2. To what degree are the governments of large developing countries, such as China and India, taking an interest in climate change research and attempting to mitigate further damage to the environment? Do they acknowledge that climate change may be, in part, a consequence of human activity? Has a credible estimate been developed on the amounts of some pollutants released into the atmosphere by these countries?

A2. Yes, China and India have great interest in climate change, but it is also fairly clear that they are not yet doing very much to mitigate the environmental damage, arguing that they should not be asked to do anything that might hurt their economy when developed nations like the United States are doing so little. China and India both participated in the latest IPCC report and agreed with its conclusions. They both acknowledge that human activities are a significant part of the cause of global warming and climate change (an IPCC conclusion). Yes, credible estimates have been developed on the pollution emitted by these countries, and satellites have played a role in these estimates (for example, aerosols). China and India are both very large contributors to carbon dioxide and other pollutant emissions. In 2006 China moved ahead of the United States as the number one emitter of carbon dioxide. It is clear that without significant actions on the part of all nations, developing and developed, the emission of greenhouse gases and the resultant rate of climate change will only increase.

Q3. The Decadal Survey highlighted the importance of developing a strategy to transition technologies from NASA to operational systems. How is transition managed today? What steps can NASA take to improve technology transition between researchers and the applications community?

A3. Frankly speaking, very little of substance has been done to facilitate the transition of research to operations since the 2003 NRC report *Satellite Observations of the Earth's Environment-Accelerating the Transition of Research to Operations.* That report recommended the formation of a joint NASA–NOAA Interagency Transition Office to develop and implement a strategy to transition NASA research into NOAA operations. As we said in the Decadal Survey, "An efficient and effective Earth observation system requires an ongoing interagency evaluation of the capabilities and potential applications of numerous current and planned missions for transition of fundamental science missions into operational observation programs. *The committee is particularly concerned with the lack of clear agency responsibility for sustained research programs and the transitioning of proof-of-concept measurements into sustained measurement systems.* To address societal and research needs, both the quality and the continuity of the measurement record must be assured through the transition of short-term, exploratory capabilities, into sustained observing systems.

Transition failures have been exhaustively described in previous reports and the committee endorses the recommendations in these studies."

In terms of concrete steps, the Decadal Survey (Chapter 5, *Earth Science Applications and Societal Benefits*) in Part III discusses a number of important aspects of the process of realizing societal benefits from Earth observations through scientific research and application development: "These include: (1) establishing mechanisms for including priorities of the applications community in space-based missions, (2) considering studies of the value and benefits of Earth observations published in the social sciences literature, (3) creating closer institutional relationships between the science and applications (user) communities, (4) having easy availability to observations and products derived from observations by the broad user community, and (5) educating and training new users of Earth data and information, as well as facilitating the creation of a scientifically-informed and literate citizenry. Meeting these objectives will require a greater involvement of social scientists (e.g., development policy analysts, communication researchers, anthropologists, environmental economists) throughout the entire mission life cycle, in order to make certain societal needs are appropriately considered during the design process, and to ensure societal benefits are derived from the implemented observations."

ANSWERS TO POST-HEARING QUESTIONS

Responses by Eric J. Barron, Dean, Jackson School of Geosciences; Jackson Chair in Earth System Science, University of Texas, Austin

Questions submitted by Chairman Mark Udall

Q1. You testified that the Decadal Survey calls attention to the need for improved understanding of aerosol cloud forcing and ocean circulation, two areas "that are considered to be the most limiting in terms of our ability to improve climate model predictions." What potential gains in the predictive capability of climate models could we expect if the Decadal Survey's Aerosol/Cloud/Ecosystems (ACE) and Surface Water Ocean Topography (SWOT) missions were to be implemented?

A1. It is difficult to be precise in estimating the degree to which any new set of observations will improve our ability to simulate climate. Climate models have a number of uncertainties of varying importance, which may in fact compound each other or serve to obscure the relative importance of individual factors. However, the improvements can be placed into perspective in a manner that clarifies their importance.

Aerosol climate forcing is estimated as having a similar magnitude forcing as carbon dioxide, but the uncertainty is five times greater. There are several factors governing this large uncertainty: (a) aerosols have a short life time in the atmosphere, (b) not all aerosols are alike, and the differences in their character define how they influence the heating of the Earth's surface and atmosphere, and (c) aerosols indirectly influence climate through their affect on cloud formation, again a significant factor in defining the Earth's energy budget. Interestingly, the estimates of the uncertainties associated with aerosols have not changed significantly from earlier IPCC projects, indicating that we are making limited progress in this area. The ACE mission is designed explicitly to tackle this long-standing problem by enabling a better understanding of aerosol-cloud interaction through better accuracy, finer resolution and greater spatial coverage.

Ocean topography allows us to monitor sea level and the heating (thermal expansion) of the oceans. In addition, ocean topography is a measure of the ocean surface circulation. The continuous measurement of ocean surface topography since 1992 provides one of the most significant data sets available to assess the capabilities of ocean circulation models. However, SWOT offers significant improvement. Recent estimates indicate that current climate models are overestimating the heat uptake. In concert with mass measurements of a GRACE-type instrument, significant improvement in this key attribute can be obtained. In addition, the improvement of our understanding of upper ocean processes depends on our ability to resolve important features, specifically ocean eddies. Increased resolving capability can provide a detailed picture of mesoscale circulation that can be used to improve our understanding of the physics governing the ocean circulation and of the interaction between the ocean and the atmosphere, and hence provide an important foundation for improving climate models.

Q2. The Earth Science Subcommittee of the NASA Advisory Council proposed a NASA Earth Science Initiative. The proposal involves redirecting support for a planned FY08 solicitation for an Earth System Science Pathfinder to a decadal survey mission. What is your reaction to that proposal?

A2. The Decadal Survey recommends a set of critical observations with defined priorities and, in addition, a class of missions that enable a more opportunistic approach (to ensure that the program remains innovative and able to respond to new scientific discoveries). The notion of redirecting a planned FY08 solicitation for an Earth System Science Pathfinder (ESSP) to a Decadal Survey mission is a step towards achieving the Survey objectives. However, two issues become very important. First, the current NASA budget is not sufficient to achieve the Decadal Survey's priority missions. The proposal is therefore a small part of what must be a much more strategic approach to Earth observations. A successful program must follow the carefully defined set of missions described by the Decadal Survey, involving small, medium, and larger missions (costs). It is difficult to imagine that the systematic approach of the Decadal Survey can be achieved with ESSP-type missions. Second, we must ensure that the strategy of the Decadal Survey is maintained, with a systematic approach to priority missions and the inclusion of missions that can be innovative and creative. The later opportunities (proposed as Venture class missions), as described in the Decadal Survey, are very different from NASA's ESSP missions, which are largely opportunities to incorporate competition in the implementation of specific objectives.

Q3. Your testimony refers to potential restrictions on instrument information, access to data, and software that may arise in international collaborations. What would be the implications of such restrictions for climate data sets?

A3. The climate record depends on generating and sustaining long-term records in which the observational uncertainties must be smaller than the sought-for geophysical measurements. Key to a robust program is to ensure (a) overlap in time between instruments in order to identify and reduce calibration uncertainties, (b) transparency in programs for monitoring sensor calibration and performance, (c) verification of the products of analysis algorithms and the ability to reprocess data to correct errors in earlier processing algorithms, (d) improved quality of the observations within a time series (as opposed to launch of less capable instruments), (e) avoidance of orbit drift, and (f) validation of geophysical products, providing an independent check on the performance of space-based sensors and processing algorithms. Restrictions on data access, instrument information, and software clearly will restrict or raise questions about many of these keys to a robust climate record. The implication is a reduced value to the long-term investment in observation time series, largely through increased levels of uncertainty in the climate data sets.

Q4. Is there a consensus (among federal agencies, academia, and other users) on a set of climate and environmental measurements to which the nation should commit for sustained observations? If so, what is the set? If not, should there be such a set of consensus measurements and what would be involved in reaching consensus?

A4. Substantial, but not universal, consensus exists. The 2003 Global Climate Observing System (GCOS) report provides a list of climate parameters ("The second report on the adequacy of the global observing system for climate in support of the UNFCCC." GCOS–82, World Meteorological Organization, Tech. Doc 1143, 85 pp., 2003). This report was adopted by the Climate Variability and Change Panel and provides a high level of consensus on needed measurements. The Climate Variability and Change Panel then assessed current observing capabilities and those planned for the coming decade to develop a table within Chapter 9 of critical climate variables and mission needs.

More generally, the observations need to address specific requirements. Our observations must document the forces on the climate system (solar and volcanic activity, greenhouse gases and aerosols, changes in the land surface and albedo), the state of the atmosphere, ocean, ice and land surface to understand how the system is changing, the characteristics of internal variability that may obscure long-term change, and the feedback processes involving the atmosphere, land and ocean, biogeochemical cycles and the hydrologic cycle. It is the assessment of the Climate Variability and Change Panel of the status of current and planned measurements in comparison with the GCOS report that defined the critical missions proposed in the Decadal Survey.

Questions submitted by Representative Tom Feeney

Q1. To what degree are the governments of large developing countries, such as China and India, taking an interest in climate change research and attempting to mitigate further damage to the environment? Do they acknowledge that climate change may be, in part, a consequence of human activity? Has a credible estimate been developed on the amounts of some pollutants released into the atmosphere by these countries?

A1. China and India are both participants in the IPCC process and have endorsed the conclusions of the report. Certainly, this indicates a level of acknowledgement that climate is changing and is significantly a consequence of human activity. The large populations of India and China make them significant contributors to carbon dioxide and other greenhouse gases, as well as aerosols. There are reliable estimates of greenhouse gas contributions by the countries of the world, and contributions of China rival (and recently passed) those of the United States in magnitude. China has instituted a major study to look at the impacts of climate change on China, in part modeled after U.S. reports to examine the potential consequences of climate variability and change. Such research activities imply a more active interest in assessing potential damage to the environments of China. However, there is little sign of efforts to mitigate climate change. My opinion is that the economic growth within China and India is the foremost factor in setting policy. Without global agreement on emissions mitigation, between developing and developed countries, there appears to be little incentive to take action in China or India. Research studies on impacts, as they emerge, may alter this viewpoint. China's new position as the number one emitter of carbon dioxide may also result in greater world pressure to address emissions.

Q2. The Decadal Survey highlighted the importance of developing a strategy to transition technologies from NASA to operational systems. How is transition managed today? What steps can NASA take to improve technology transition between researchers and the applications community?

A2. There are two significant National Research Council Reports on the transition of NASA technologies to operational systems. The first is From Research to Operations in Weather Satellites and Numerical Weather Prediction: Crossing the Valley of Death (2000), and the second is Satellite Observations of the Earth's Environment-Accelerating the Transition from Research to Operations (2003). The investment in transitioning valuable information and technologies from NASA into operations is extremely small. The first report recommended a joint NASA-NOAA testbed for promoting transition from research to operations, and a small office was funded. The second report recommended an Interagency Transition Office to develop and implement a strategy for transition. The progress here is small and the problems are numerous. There is a lack of investment in the transition of technologies, there is a lack of clear agency responsibilities, and there is a lack of defined strategy. The consequence is that a very large amount of capability never achieves a status of serving society.

I also believe that this is not a matter of just transitioning technologies. One could cite numerous instances in which the observations, different data sets, and model capabilities of NASA and NOAA could serve different segments of society ranging from human health, water management, energy conservation, agriculture, etc. Today, we have a very small "applications" program, designed to help provide data and expertise for specifically identified needs of society where NASA or NOAA data can be useful. This is valuable, but, in fact, we have the potential to do much more to benefit society. For example, we have the potential to develop predictive models for adverse human health outcomes related to the environment (including weather and climate), but this requires active, collaborative research in environmental health that brings together climate researchers with the medical community to define the connections and relationships that will enable such predictive capability. Such outcomes don't occur simply by providing data sets, it occurs by deliberately investing in areas that have the potential to transform our large investment in NASA and NOAA into societal benefits.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Timothy W. Foresman, President, International Center for Remote Sensing Education

Questions submitted by Chairman Bart Gordon

Q1. According to the report of the MODIS Science Team, as documented in The Earth Observer *publication, "The use of MODIS data for land studies has exceeded even our most optimistic expectations and has been an unprecedented success for NASA's terrestrial program." Will follow-on sensors to MODIS have the capability to support the growing number of applications derived from MODIS data? If not, what will be the impact?*

A1. MODIS is an experiment. If MODIS was to become operational, then a growing number of applications could depend upon the platform. Continuity of the sensors and the MODIS program would have to be carefully discussed with the user community and appropriate government agencies (e.g., NOAA, USGS) to define any operational scenarios.

Questions submitted by Chairman Mark Udall

Q1. Could you please discuss some of the applied uses of Landsat data?

A1. There are so many applied uses of Landsat data that any single treatment will not do justice. The applications in use over the past thirty-five years include a broad range of civil engineering uses, public health and disease vector monitoring uses, master planning and urban design, water resources, forestry, and a litany of environmental uses. I used Landsat data on behalf of the Department of Defense for both environmental work and for war planning in the middle east. I use Landsat data for a variety of projects while working for the US EPA. And Landsat traveled with me to the United Nations where good use has been applied to studying the dynamics of the planet over a three-decade period. There has been not substitute for this powerful tool.

Q1a. What are the potential implications of any disruptions in the long-term Landsat data record for the applied uses of the data?

A1a. Disruptions would be a great disservice to the U.S. and the world. It would be akin to not taking x-rays of your teeth for a ten years after carefully maintaining your dental health. There is no suitable replacement. If the U.S. allows a disruption, the science community and the state and county managers will be at a significant loss.

Q1b. What scientific and operational value do the thermal imaging data of the Landsat program provide?

A1b. Thermal data has proven to be extremely valuable for a variety of environmental and energy related applications. As energy becomes more adult in the workings of communities, they will find more use for the thermal bands.

Q2. Your testimony refers to non-governmental organizations and their use of Earth science data to address societal needs. Is there an appropriate role for NASA in supporting these activities through technical assistance, training, data access, or other means?

A2. It is my opinion that NASA could provide a great service for the many NGOs around the country and world. NASA has subsidized a variety of commercial businesses, but has not been vary successful with the NGOs. A better understanding of the challenges, missions, and scale of assistance to NGOs would provide society with many benefits.

Questions submitted by Representative Tom Feeney

Q1. The Decadal Survey highlighted the importance of developing a strategy to transition technologies from NASA to operational systems. How is transition managed today? What steps can NASA take to improve technology transition between researchers and the applications community?

A1. NASA would require outside expert assistance from experienced business professionals to handle the transition of technologies to operational status. The mindset and experience in NASA does not allow for high success in transitions. Many transitions, however, would be best supported by quasi-government arrangements as the sensors may be more scientific in nature and use and not lend themselves to commercial enterprise. The major of sensors fall into this category.

Q2. Your statement recommends that NASA "include Earth as its primary planet of study and Earth sciences at its core." What do you mean by this statement? Are you suggesting that NASA abandon or seriously reduce other lines of space research?

A2. As the former chief environmental scientist for the United Nations, it is my opinion that the scarce resources be applied to studying and monitoring the Earth's systems as the alarming rates of extinction, land and soil degradation, and ecosystem collapses will impact current and future generations. Robotic missions are the most cost effective and allow for widespread web-collaboration among students and scientists around the globe. I would strongly recommend that space exploration be re-engineered to focus on remote sensing and robotics and not squander precious time and resources on human-oriented lunar and Mars missions.

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