Statement of

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Mr. Chairman, Ranking Minority Member, and members of the committee: thank you for inviting me here to testify today. My name is Berrien Moore, and I am a professor of systems research at the University of New Hampshire and Director of the Institute for the Study of Earth, Oceans, and Space. I appear today, like Dr. Anthes, in my capacity as co-chair of the National Research Council (NRC)'s Committee on Earth Science and Applications from Space.

As you know, the NRC is the unit of the National Academies that is responsible for organizing independent advisory studies for the federal government on science and technology. The NRC has been conducting decadal strategy surveys in astronomy for four decades, but this is the first decadal survey in Earth science and applications from space.

On March 2, 2006, I testified before this committee at a hearing entitled, *NASA's Science Mission Directorate: Impacts of the Fiscal Year 2007 Budget Proposal*. At that hearing, I showed the table below, which is taken from the 2005 Interim Report of our study. This table shows the effects of the FY '06 budget.[1] I then discussed my concerns about the proposed cuts in the FY '07 budget, especially the continuing reductions in funding for Research and Analysis, which I believed was having a very negative effect on a program already pared to the bone.

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

[1] Note that the Glory mission was subsequently restored. The latest plan for LDCM is to implement the mission as a free-flyer.

Glory	Optical properties of aerosols; solar irradiance	Improved scientific understanding of factors that force climate change	Canceled
Wide Swath Ocean Altimeter (on the Ocean Surface Topography Mission, OSTM)	Sea level in two dimensions	Monitoring of coastal currents, eddies, and tides, all of which affect fisheries, navigation, and ocean climate	Instrument canceled—descope of an enhanced OSTM

Since my appearance, there have been further cancellations and delays of NASA missions and dramatic and deleterious changes in plans for the next generation of NOAA meteorological satellites, especially regarding their capability to support the needs for prediction, assessment, and mitigation of the effects of climate change.

With this as background, I will now turn to the questions posed to me in advance of this hearing.

1. How did the Decadal Survey committee determine the priorities that it recommended the nation pursue in Earth and climate science research and applications?

As noted in testimony of my co-chair, Dr. Richard Anthes, the decadal survey's vision, which was first expressed in the committee's 2005 Interim Report,[2] is for a program of Earth science research and applications in support of society. The present report reaffirms this vision, the fulfillment of which requires a national commitment to a program of Earth observations from space in which practical benefits to humankind play an equal role with the quest to acquire new knowledge about the Earth.

The Interim Report described how satellite observations have been critical to scientific efforts to understand the Earth as a system of connected components, including the land, oceans, atmosphere, biosphere, and solid-Earth. It also gave examples of how these observations have served the nation, helping to save lives and protect property, strengthening national security, and contributing to the growth of our economy[3] through provision of timely environmental information. However, the Interim Report also identified a substantial risk to the continued availability of these observations, warning that the nation's system of environmental satellites was "at risk of collapse." As noted above, in the short period since the publication of the Interim Report, budgetary constraints and programmatic difficulties at NASA and NOAA 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.

[2] National Research Council, *Earth Science and Applications from Space: Urgent Needs and Opportunities to Serve the Nation*, The National Academies Press, Washington, D.C., 2005.

[3] It has been estimated that one third of the $10 trillion U.S. economy is weather-sensitive or environment-sensitive (NRC, *Satellite Observations of the Earth's Environment: Accelerating the Transition of Research to Operations*, The National Academies Press, Washington, D.C., 2003).

The decadal survey was led by an Executive Committee that drew on the work of seven thematically-organized study panels[4]:

1. Earth science applications and societal needs.
2. Land-use change, ecosystem dynamics, and biodiversity.
3. Weather (including space weather[5] and chemical weather[6]).
4. Climate variability and change.
5. Water resources and the global hydrologic cycle.
6. Human health and security.
7. Solid-Earth hazards, resources, and dynamics.

As described in Chapter 2 of our final report, each of the panels used a common template in establishing priority lists of proposed missions (see Table 1 below). The potential to deliver tangible benefits to society was an overriding consideration for panel deliberations.

Because execution of even a small portion of the missions on the panels' short lists was not considered affordable, panels worked with each other and with members of the Executive Committee to pare the number of missions; they also developed synergistic mission "rollups" that would maximize science and application returns across the panels while keeping within a more affordable budget. Frequently, the recommended missions represented a compromise in an instrument or spacecraft characteristic (including orbit) between what two or more panels would have recommended individually without a budget constraint.

All the recommendations offered by the panels would merit support—indeed, the panels' short lists of recommendations were distilled from the over 100 responses that we received in response to a request for mission concepts, as well as other submissions—but the Executive Committee took as its charge the provision of a strategy for a strong, balanced national program in Earth science for the next decade that could be carried out with what are thought to be realistic resources. Difficult choices were inevitable, but the recommendations presented in this report reflect the committee's best judgment, informed by the work of the panels and discussions with the scientific community, about which programs are most important for developing and sustaining the Earth science enterprise.

The recommended NASA program can be accomplished by restoring the Earth science budget in real terms to the levels of the late 1990s.

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[4] The Panel Chairs were members of the Executive committee

[5] The term *space weather* refers to conditions on the Sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and that can affect human life and health.

[6] There is no single definition of *chemical weather*, but the term refers to the state of the atmosphere as described by its chemical composition, particularly important variable trace constituents such as ozone, oxides of nitrogen, and carbon monoxide. Chemical weather has a direct impact in a number of areas of interest for this study, especially air quality and human health.

TABLE 1. The eight prioritization criteria used by the panels to create relative rankings of missions. Note that these are guidelines; they are not in priority order, and they may not reflect all of the criteria considered by the panels.

1. Contribution to the most important scientific questions facing Earth sciences today (scientific merit, discovery, exploration)
2. Contribution to applications and policy making (societal benefits)
3. Contribution to long-term observational record of the Earth
4. Ability to complement other observational systems, including national and international plans
5. Affordability (cost considerations, either total costs for mission or costs per year)
6. Degree of readiness (technical, resources, people)
7. Risk mitigation and strategic redundancy (backup of other critical systems)
8. Significant contribution to more than one thematic application or scientific discipline

2. What are the practical benefits of the research and applications activities that your Decadal Survey recommended?

Our report presents a vision for the Earth science program; an analysis of the existing Earth observing system and recommendations to help restore its capabilities; an assessment of and recommendations for new observations and missions needed for the next decade; an examination of and recommendations concerning effective application of those observations; and an analysis of how best to sustain that observation and applications system. *A critical element of the study's vision is its emphasis on the need to place the benefits to society that can be provided by an effective Earth observation system on a par with scientific advancement.*

The integrated suite of space missions and supporting and complementary activities that are described in our report will support the development of numerous applications of high importance to society. Expected benefits of the fully-implemented program include:

- **Human Health**
  More reliable forecasts of infectious and vector-borne disease outbreaks for disease control and response.
- **Earthquake Early Warning**
  Identification of active faults and prediction of the likelihood of earthquakes to enable effective investment in structural improvements, inform land-use decisions, and provide early warning of impending earthquakes.
- **Weather Prediction**
  Longer-term, more reliable weather forecasts.
- **Sea Level Rise**
  Climate predictions based on better understanding of ocean temperature and ice

sheet volume changes and feedback to enable effective coastal community planning.

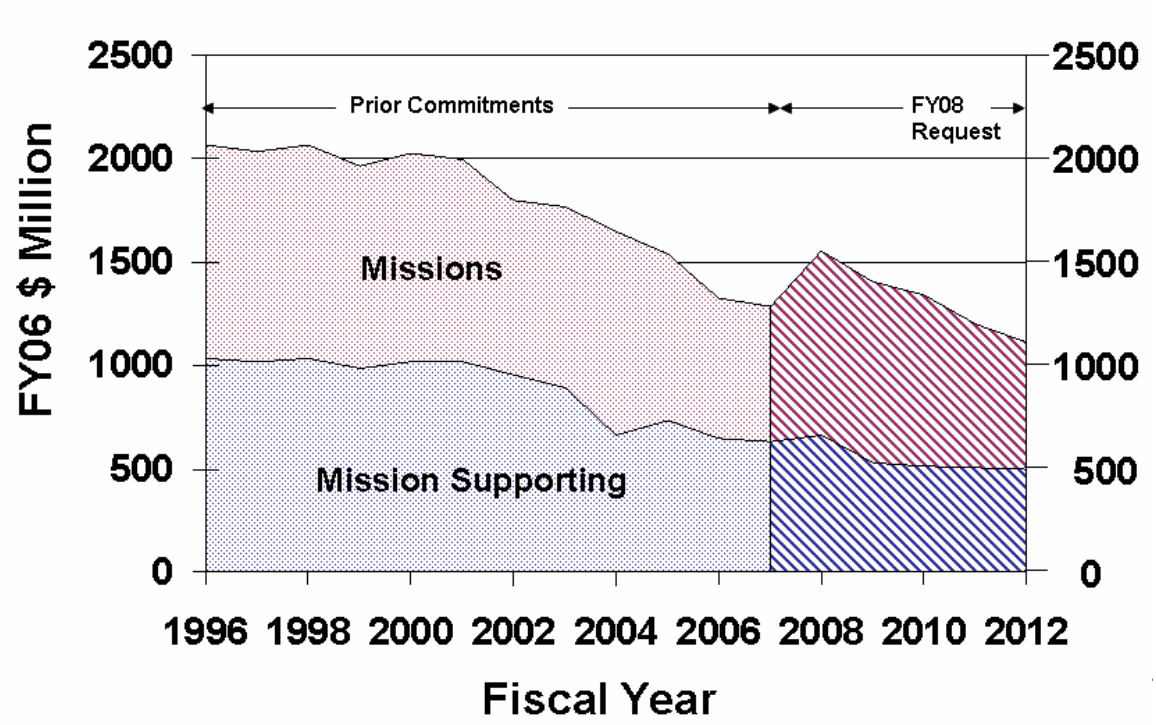
- **Climate Prediction**
  Robust estimates of primary climate forcings for improved climate forecasts, including local predictions of the effects of climate change; determination in time and space of sources and sinks of carbon dioxide.
- **Freshwater Availability**
  More accurate and longer-term precipitation and drought forecasts to improve water resource management.
- **Ecosystem Services**
  More reliable land-use, agricultural, and ocean productivity forecasts to improve planting and harvesting schedules and fisheries management.
- **Air Quality**
  More reliable air quality forecasts to enable effective urban pollution management.
- **Extreme Storm Warnings**
  Longer-term, more reliable storm track forecasts and intensification predictions to enable effective evacuation planning.

3. How consistent is the President's FY 2008 budget request for NASA and NOAA with the recommendations of the Decadal Survey Committee?

It is important to note we were, of course, not privy to the details of the President's fiscal year 2008 budget, which was developed prior to the release of our final report. The NRC report is a forward-looking document and therefore focuses primarily on the new missions; whereas, the Interim Report dealt with the difficulties and challenges of the Earth observing programs at NASA and NOAA, as they existed in early 2005.

Let me address first the President's FY '08 budget request for NASA Earth science. It is a mixture of some good news and bad news. The primary good news is the small bottom line increases for 2008 and 2009. These increases address the needs of currently planned missions already in development, the completion of which is consistent with the decadal survey's baseline set of assumptions. *Unfortunately, the out-year budgets reveal fundamental flaws in the budget and NASA's Earth science plans* - the budgets are totally inadequate to accomplish the decadal survey's recommendations.

In 2010, the Earth science budget begins to decline again and reaches a 20-year low, in real terms, in 2012. This decline reflects that the 2008 budget contains no provision for new missions, nor does it allow us to address the significant challenges facing our planet. The 2008 budget also ignores our repeatedly stated concern about declines in the Research and Analysis portion of the Earth science budget. The Interim Report raised this concern about the FY 2006 budget and the importance of a robust Research and Analysis program is reaffirmed in the final report, but regrettably, the FY 08 budget for R&A is 13% below the FY '06 budget in real terms. These disturbing broad trends are captured in Figure 1.



Mission supporting activities include Earth Science Research, Applied Sciences, Education and Outreach, and Earth Science Technology.

Before turning to NOAA, I want to emphasize that the problems in the out-years appear to be due entirely to the lack of adequate resources. In fact, at a NASA town hall meeting that followed the release of our report on January 15, 2007 at the 2007 annual meeting of the American Meteorological Society, the head of NASA's Earth Science program stated that the recommendations in our report provided the roadmap for the Earth Science program we *should* have.

The NOAA NESDIS budget picture is also a mixture of some good and bad news. In this case, the budget takes a small downturn in FY08, followed by significant growth in FY09–FY10, before turning down again in FY11 (Figure 2). It remains to be seen whether this ~$200 M/year growth in FY09 and FY10 can enable restoration of some of the lost capabilities to NPOESS and GOES-R. There appears to be no budgetary wedge for new starts. Finally, for a variety of reasons, the NOAA NESDIS budget is far from transparent, especially in the out-years, and the level of detail that is readily available makes it difficult to respond adequately to Committee's question.

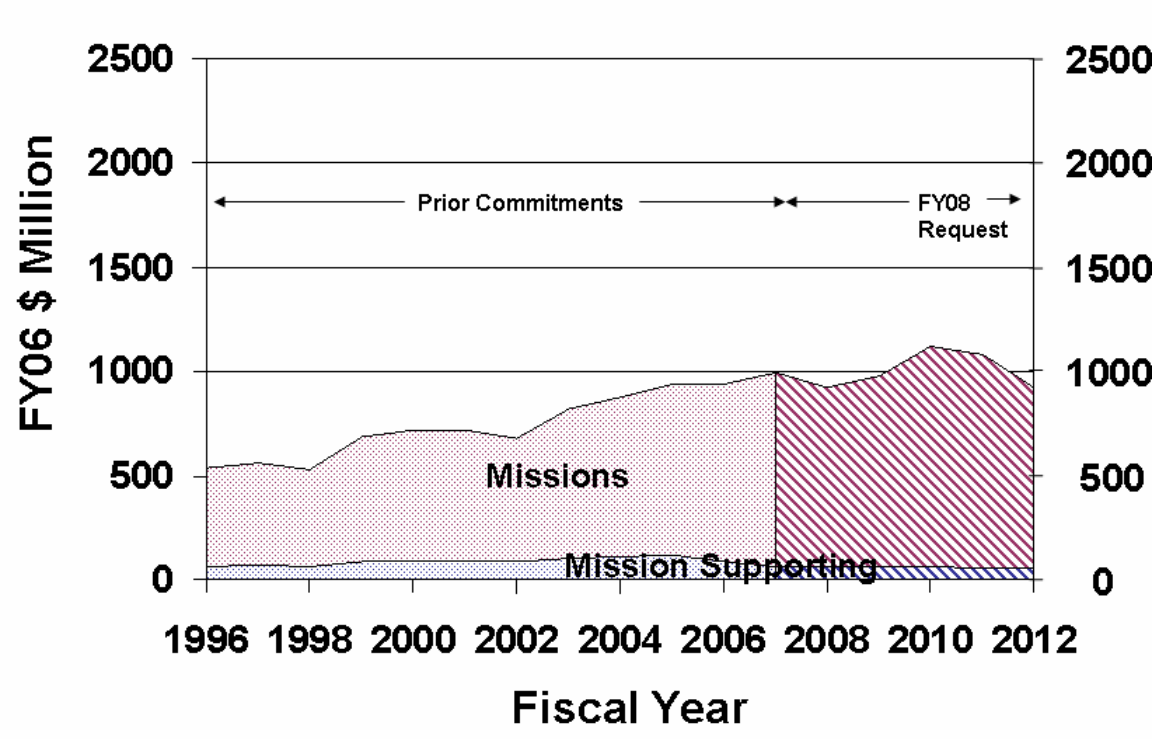


Figure 2: The NOAA NESDIS Budget in constant 2006 dollars (assumes 3 percent/year inflation from 2006-2012). Mission supporting activities include NOAA's Data Centers and Information Services, Data System Enhancements, Data Exploitation, and Information Services, and Facilities and Critical Infrastructure Improvements.

4. What will be the impact if present trends in Earth and climate science research and applications investments continue?

As detailed in our report and as summarized by my co-chair, between 2006 and the end of the decade, the number of operating U.S. missions will decrease dramatically and the number of operating sensors and instruments on NASA spacecraft, most of which are well past their nominal lifetimes, may decrease by some 35 percent. If present trends continue, reductions of some 50% reduction are possible by 2015.

Were this to pass, we would have chosen, in effect, to partially blind ourselves at a time of increasing need to monitor, predict, and develop responses to numerous global environmental challenges. Vital climate records, such as the measurement of solar irradiance and the Earth's response, will be placed in jeopardy or lost. Measurements of aerosols, ozone profiles, sea surface height, sources and sinks of important greenhouse gases, patterns of air and coastal pollution, and even winds in the atmosphere are among the numerous critical measurements that are at risk or simply will not occur if we follow the path of the President 2008 budget and the proposed out-year run out.

Taking this path, we will also forgo the economic benefits that would have come, for example, from better management of energy and water, and improved weather predictions.[7] Again, as my co-chair notes in his comments and testimony, without action on the report's recommendations, a decades-long improvements in the skill in which we make weather forecasts will stall, or even reverse; this may be accompanied by diminished capacity to forecast severe weather events and manage disaster response and relief efforts. The nation's capabilities to forecast space weather will also be at risk, with impacts on commercial aviation and space technology.[8]

The world is facing significant 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 the likelihood of significant changes in climate. These changes are occurring over and above the stresses imposed by the natural variability of a dynamic planet, as well as the effects of past and existing patterns of conflict, poverty, disease, and malnutrition. Further, these changes interact with each other and with natural variability in complex ways that cascade through the environment across local, regional, and global scales. In summary,

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[7] In a typical hurricane season, NOAA's forecasts, warnings, and the associated emergency responses result in a $3 billion savings. Two-thirds of this savings, $2 billion, is attributed to the reduction in hurricane-related deaths, and one-third of this savings, $1 billion, is attributed to a reduction in property-related damage because of preparedness actions. Advances in satellite information, data assimilation techniques, and more powerful computers to run more sophisticated numerical models, have lead to more accurate weather forecasts and warnings. Today, NOAA's five-day hurricane forecasts, which utilize satellite data, are as accurate as its three-day forecasts were 10 years ago. The additional advanced notice has a significant positive effect on many sectors of our economy. See statement and references therein of Edward Morris, Director, Office of Space Commercialization, NOAA, Hearing on Space and U.S. National Power, Committee on Armed Services Subcommittee on Strategic Forces, U.S. House of Representatives, June 21, 2006. Available at: <http://www.legislative.noaa.gov/Testimony/morris062106.pdf>.

[8] Ibid.

absent a reversal of the present trends for Earth observation capabilities, we see the following:

- **Weather forecasts**: After decades of steady improvement, weather forecasts, including those of severe weather such as hurricanes, may become less accurate, putting more people at risk and diminishing the proven economic value of accurate forecasts.
- **Earthquakes, tsunamis, landslides, and volcanic eruptions**: We risk missing early detection of these and other hazards. We also lose our ability to assess damage and mitigate the loss of further human life once they have occurred. Satellite monitoring of volcanic plumes, for example, has a very real impact on air traffic control.
- **Water resources**: We lose many of the needed observations to monitor the health of our water storage reservoirs, and predict droughts with sufficient time to mitigate their impact.
- **Oceans**: Sea level is rising and ice around the world is melting, yet there is uncertainty in how fast these are occurring and whether or not they are accelerating or decelerating. We will become less able address these issues, and assess their implications for our coastal communities.
- **Climate**: We are losing critical observations of the Earth system, the atmosphere, oceans, land, and ice needed to verify and improve the climate models. These models will be increasingly important to the U.S. economy because they best capture the likely patterns of future climate change and variability.
- **Ecosystems**: We lose the ability to assess the health of our forests, wetlands, coastal regions, fisheries, and farmlands and to determine the impact and effectiveness of regulations designed to protect our food supply.
- **Health**: Land-use, land cover, oceans, weather, climate, and atmospheric information observations, now used by public health officials to determine the effects of infectious diseases, skin cancers, chronic and acute illnesses resulting from contamination of air, food, and water are all at risk. As an example, air quality forecasts, which use the global perspective of satellites to identify pollution transport across borders, will become less accurate, with negative implications for both human health and urban pollution management efforts.

I would like to thank the Committee for inviting me to testify, and I would be delighted to answer any further questions.