Paper J1.2

EARTH SCIENCE AND APPLICATIONS FROM SPACE: INITIAL RESULTS OF DECADAL STUDY AND A PROGRESS REPORT

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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 for society as it seeks to achieve prosperity and sustainability.

1. INTRODUCTION

The above vision, from *Earth Science and Applications from Space – Urgent Needs and Opportunities to Serve the Nation* (NRC, 2005, available at: www.nap.edu/catalog/11281.html), sets the foundation for a future strategy of Earth sciences observations from space. As shown by a remarkable 12 months of natural disasters around the world, including the Tsunami of December 2004, Hurricane Katrina of August 2005 and the Pakistan Earthquake in September 2005, the need for global observations of the Earth, the information and predictions derived from these observations, and an effective societal response has never been greater. Progress over the past 50 years in developing Earth satellites, which now form the backbone of the global observing system, has been dramatic, with great benefits to science and societal applications. Yet, the interim report sounds an alarm that all is not well with the present direction of the nation's environmental satellite system: "Today, this system of environmental satellites is at risk of collapse." Since the report was issued in April, the United States has endured one of the worst hurricane seasons in history. The societal impacts of these storms, while huge, were greatly mitigated by generally excellent forecasts, demonstrating the importance and value of a robust observational system from space (an example – Hurricane Katrina – is provided in Appendix A). But since April, new issues with NPOESS have emerged, threatening delays and loss of capabilities and underscoring the alarm call sounded in the Interim Report.

The Interim Report is the first product from the NRC "decadal survey" of Earth Science and Applications from Space (ESAS). At the request of NASA, NOAA and the USGS and developed in consultation with members of the Earth science community, the goal of the study is to set an agenda for observations in support of Earth science and applications from space in which attaining practical benefits for humankind plays a role equal to that of acquiring new knowledge about Earth.* These benefits range from weather warnings for the protection of life and property, to the development of longer-term scientific understanding that is the lifeblood of future societal applications, the details of which are not predictable.

2. BACKGROUND OF STUDY

The confluence of several factors initiated this first "decadal study" for the Earth sciences:

- NASA is nearing completion of the deployment of the Earth Observing System (EOS) and is now considering an appropriate strategy for follow-on exploratory and systematic missions.

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* Development of the study's vision drew on information received in response to a widely distributed request for comments; a request for information on new missions and concepts; town-hall style discussions at the December 2004 meeting of the American Geophysical Union and the January 2005 meeting of the American Meteorological Society; committee discussions at a workshop held on August 23-25, 2004, in Woods Hole, MA; and discussions at committee meetings held on November 8-9, 2004, in Washington, DC; January 4-6, 2005, in Irvine, CA; August 28-September 1, 2005 in Irvine; and October 25-26, 2005 in Washington, DC.

- Over the next decade, NASA will transition a number of environmental measurements from research-oriented programs to operationally oriented ones.

- In the next decade, NOAA will launch the National Polar-orbiting Operational Environmental Satellite System (NPOESS) – successors to the current generation of civil (POES) and military meteorological (DMSP) polar orbiting satellites, which will be used to monitor global environmental conditions and collect and disseminate data related to weather, atmosphere, oceans, land, and near-space environment.

- Some 33 countries, including the members of the G-8, were represented at the ministerial level at the July 31, 2003 "Earth Observations Summit" in Washington, DC. This and subsequent meetings led to the concept of Global Earth Observing System of Systems, (GEOSS) http://earthobservations.org/.

The decadal study for the Earth sciences was charged to:

1. Review the status of the field to assess recent progress in resolving major scientific questions outlined in prior NRC, NASA, NOAA, and other studies and in realizing desired predictive and applications capabilities via space-based Earth observations.

2. Develop a consensus of the top-level scientific questions that should provide the focus for Earth and environmental observations in the period 2005-2015.

3. Take into account the principal users of these observations, including a range of applications with direct links to societal objectives, and identify opportunities and challenges to the exploitation of the data generated by Earth observations from space.

4. Recommend a prioritized list of measurements and identify potential new space-based capabilities and supporting activities within NASA, NOAA and USGS to support national needs for research and monitoring of the dynamic Earth system during the decade 2005-2015. In addition to elucidating the fundamental physical processes that underlie the interconnected issues of climate and global change, these needs include: weather forecasting; seasonal climate prediction; aviation safety; natural resources management; agricultural, forestry, and ecological assessments; homeland security; and infrastructure planning.

5. Identify important directions that should influence planning for the decade beyond 2015. For example, the Committee will consider what ground-based and *in situ* capabilities are anticipated over the next 10-20 years and how future space-based observing systems might leverage these capabilities. The Committee will also give particular attention to strategies for NOAA to evolve current capabilities while meeting operational needs to collect, archive, and disseminate high quality data products related to weather, climate, oceans, land, solid Earth, and the near-space environment.

The study was initiated with a workshop in Woods Hole, MA on August 23-25, 2004. At this workshop, more than 50 participants and the Executive Committee agreed upon a number of guiding principles and criteria for prioritizing new missions and observational programs.

The study is being carried out by an Executive Committee and seven panels organized along societal themes (see Appendix B). This organization is similar to the structure that was employed by the NRC for its astronomy and astrophysics surveys and for recently completed decadal surveys in planetary exploration and solar and space physics (please see the study website at: http://qp.nas.edu/decadalsurvey for links to these studies, and for much more information about the present study).

With this structure, disciplines such as oceanography and atmospheric chemistry, although not visible in the title of a given panel, will influence the priorities of several panels not just one. All Panels are interacting with the Executive Committee throughout the study process. The Chairs of each of the seven Panels are members of the Executive Committee.

To obtain broad input from the community regarding potential future observations and associated systems to meet science and societal needs, the Committee issued a request for information (RFI) in January 2005. The response from the community was strong, with over 100 concept papers submitted (the RFI and the responses are available on the study website). The RFI gave guidelines for proposing new measurements or concepts for measurements and described the criteria that would be used by the Committee to prioritize new missions (see above). A strong message to the Committee from NASA, NOAA and the Congress is that the Decadal Study must put its recommendations in priority order.

The Committee's final report is expected in late 2006. The purpose of the Interim Report, which was requested by the sponsors of the study and congressional staff members, was to provide an early indication of urgent, near-term issues that require attention prior to publication of the Committee's final report.

2.1 *Guiding Principles for the Study*

1. Vision: The Committee will identify a compelling vision that can be summarized in one paragraph for Earth science and applications in the next decade and build the study around this vision. The vision must resonate with the scientific community as well as with Congress, OMB, and the public.

2. Connecting to societal needs: The study will use existing documents and other input to identify societal needs, including advances in scientific knowledge, and will use societal needs as important criteria for prioritizing measurements and/or missions.

3. Study purpose: The study will examine research and operational uses of spaceborne measurements for observing the Earth as well as recommend and prioritize programs and classes of missions for space-based science and applications. Although the focus will be on satellite observations, the study will also consider related aspects, such as complementary *in situ* measurements, education and training, computational requirements, modeling, assimilation, data management, organizational issues, and technology development.

4. Foundation of existing studies and programs: The study will build on existing national and international science plans, synthesizing priorities laid out in these plans, identifying gaps and additions as needed, and assessing lessons learned over the last decade to guide the next generation of Earth observations from space.

5. Scope of disciplines: The study will consider science and applications in the context of the Earth as a system. It will address all needed disciplines to accomplish this task, including all relevant natural sciences and both the human behavior and decision support elements of the social sciences.

6. Decadal planning horizon: The study will primarily address science and applications priorities and planning needs for the next decade, but it will also identify general directions for the following decade or longer as needed to facilitate future planning.

7. National context: The study will recommend mission priorities and related programs to NASA, NOAA, and other federal agencies within the broader context of U.S. Earth science and applications activities.

8. Community voice: The study will seek to create a community voice through an open and transparent study process and to communicate a consensus community vision and strategy to policy-makers and the general public.

9. Costs: The process will consider approximate costs as one of the prioritization criteria, and the study recommendations will fit within a realistic funding envelope.

2.2 *Prioritization Criteria*

1. Contributes to the most important scientific questions facing Earth sciences today (scientific merit, discovery, exploration);

2. Contributes to applications and policy making (societal benefits);

3. Contributes to long-term observational records of the Earth;

4. Complements other observational systems, including national and international plans;

5. Affordable (cost considerations, either total cost for a research mission or cost per year for an operational system);

6. Degree of readiness (technical, resources, people);

7. Risk mitigation and strategic redundancy (backup of other critical systems); and

8. Makes a significant contribution to more than one thematic application or scientific discipline.

3. SUMMARY OF INTERIM REPORT*

The Interim report describes how the 1980s and 1990s saw the emergence of a new paradigm for understanding our planet—observing and studying Earth as a system of interconnected parts including the land, oceans, atmosphere, biosphere, and solid Earth. At the same time, satellite observing systems came of age and produced new and exciting perspectives on Earth and how it is changing. By integrating data from these new observation systems with *in situ* observations, scientists were able to make steady progress in the understanding of and ability to predict a variety of natural phenomena, such as tornadoes, hurricanes, and volcanic eruptions, and thus help mitigate their consequences. (The example of Hurricane Katrina shows how observations and the models that used the observations were responsible for excellent forecasts of Katrina 60 hours in advance, giving time for about 80% of the population of New Orleans to evacuate – see Appendix A.) Decades of research investments and the present Earth observing system have also improved health, enhanced national security, and spurred economic growth by supplying the business community with critical environmental information.

Yet even this progress has been outpaced by society's ongoing need to apply new knowledge to expand its economy, protect itself from natural disasters, and manage the food and water resources on which its citizens depend. The aggressive pursuit of understanding Earth as a system—and the effective application of that knowledge for society's benefit—will increasingly distinguish those nations that achieve and sustain prosperity and security from those that do not. In this regard, recent changes in federal support for Earth observation programs are alarming. At NASA, the vitality of Earth science and application programs has been placed at substantial risk by a rapidly shrinking budget that no longer supports already-approved missions and programs of high scientific and societal relevance. Opportunities to discover new knowledge about Earth are diminishing as mission after mission is cancelled, descoped, or delayed because of budget cutbacks. In addition, transitioning many of the scientific successes at NASA into operational capabilities at NOAA and other agencies have failed to materialize, years after the potential and societal needs were demonstrated, even as the United States has announced that it will take a leadership role in international efforts to develop integrated, global observing systems.

In the interim report, the Committee identified a number of issues that require immediate attention and recommended actions to meet current critical needs:

- Proceed with some NASA missions that have been delayed or cancelled,
- Evaluate plans for transferring needed capabilities from some cancelled or descoped NASA missions to NPOESS,
- Develop a technological base for exploratory Earth observation systems,
- Reinvigorate the Explorer missions program,
- Strengthen research and analysis programs, and
- Strengthen the approach to obtaining important climate observations and data records.

The full set of recommendations may be read in the report at www.nap.edu/catalog/11281.html.

4. COMPLETING THE STUDY

The website http://qp.nas.edu/decadalsurvey describes the study, includes many relevant documents and plans, and provides an opportunity for community input throughout the process. In addition, a number of additional outreach activities are being planned, including community forums in conjunction with the Fall 2005 AGU meeting and the American Meteorological Society meeting in January 2006.

Over the next several months, the Executive Committee and the Panels will interact to produce the final report. This report will consist of a summary of the process, principles, and criteria for prioritization; the vision describing the intellectual challenges and societal benefits; and reports from the seven Panels. The concluding chapter will describe a way forward, including prioritized measurements, missions, correlative needs, and necessary technology development.

* Much of this summary is taken from the Executive Summary of the Interim Report.

Observing and understanding the Earth and applying this understanding to societal benefits are essential to the health, prosperity, and security of the nation and the world. If we succeed in meeting the challenge of developing a long-term observational strategy that effectively recognizes the importance of societal benefits, a strong foundation will be established for research and operational Earth sciences in the future, to the great benefit of society—now and for generations to come.

APPENDIX A: THE VALUE OF EARTH OBSERVATIONS, SCIENCE AND APPLICATIONS: LESSONS LEARNED FROM HURRICANE KATRINA

Much has been written about the failures of society and government on all levels that contributed to the 2005 Katrina disaster. But relatively little attention has been paid to the superb quality of the government forecasts. The forecast issued by the National Hurricane Center (part of NOAA's National Weather Service) late Friday night, August 26th, placed Katrina just east of New Orleans on Monday, August 29th. The subsequent forecasts were remarkably consistent, and they made a huge difference. Without them and the evacuations they triggered, emergency responders would have had roughly five times as many people to rescue from the wind, floods, and chaos, and many more lives would have been lost.

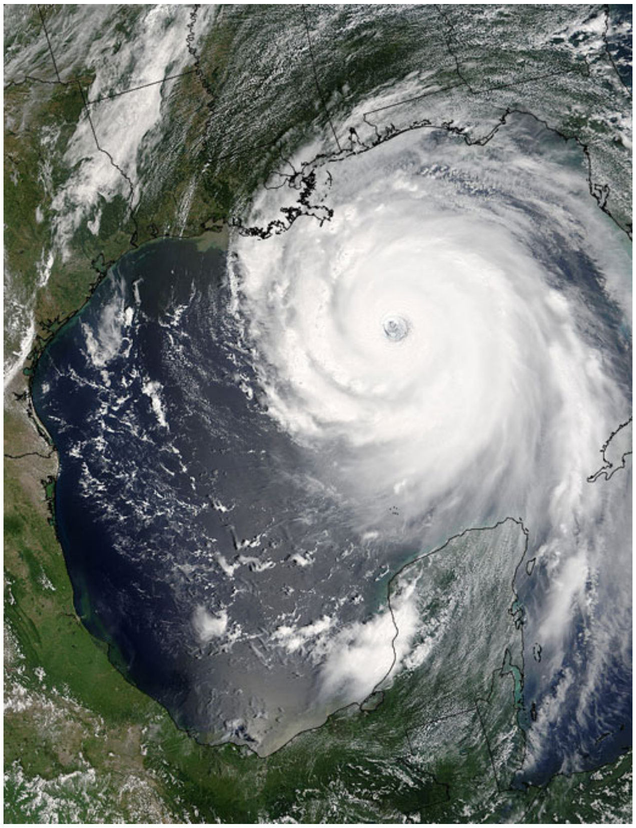
The excellent forecasts proved their worth, but they stand only at the most visible end of a complex scientific and technological system that has taken years to develop. Much of this system is largely invisible to the public and to most policy-makers. In fact, the accuracy of forecasts of hurricane tracks has increased steadily over the years, especially over the last decade. The reasons include new and better observations (especially satellite data), improved computer models that can incorporate the new data, and faster computers, which are required to run the models. Overarching all of these factors is science—the advances that allow researchers and engineers to build the satellites and their instruments, to process the data, to incorporate them in the models, and to improve the models themselves.

The excellent forecasts for Katrina, Rita, Wilma and other storms this year did not just happen by chance, but as the result of public investment in science and technology in government laboratories and universities. All of these reasons for the excellent hurricane forecasts must be understood and remembered. They form the foundation for a strategy to move forward to improve forecasts of hurricanes and other natural disasters in the future.

Two of the most important and enduring lessons from the Katrina disaster will be the extraordinary value of federal investments in research and education and the indispensability of satellite observation systems. Some examples are shown below. Even without the unique factors that came together in New Orleans with Katrina, and even without the very real risk of climate change, similar disasters (winter storms, floods, droughts, earthquakes, heat and cold waves) will happen again and again. It is essential that we learn from this year's hurricanes and act in fundamentally different ways to prepare for the future.

The following photographs and images were taken from a NASA website: http://www.nasa.gov/vision/earth/lookingatearth/h2005_katrina.html

They show some different ways of observing from space Hurricane Katrina and the impacts following the storm. These observations are essential for improving scientific understanding and operational predictions of hurricanes.



MODIS (Moderate Resolution Imaging Spectroradiometer) image of Hurricane Katrina on Sunday, August 28, 2005 at 1700 UTC. This image was taken from NASA's Terra satellite.

Credit: NASA/Jeff Schmaltz, MODIS Land Rapid Response Team http://rapidfire.sci.gsfc.nasa.gov/

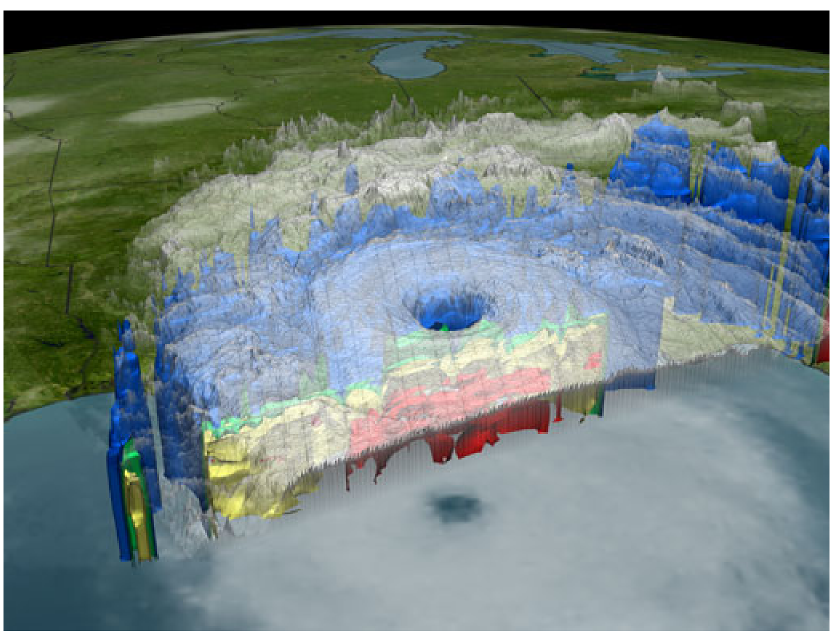
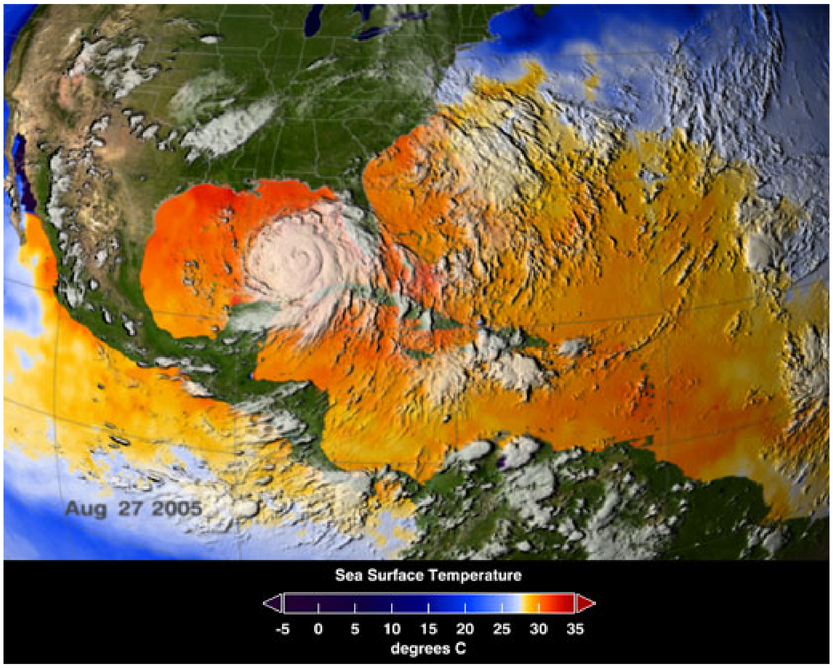
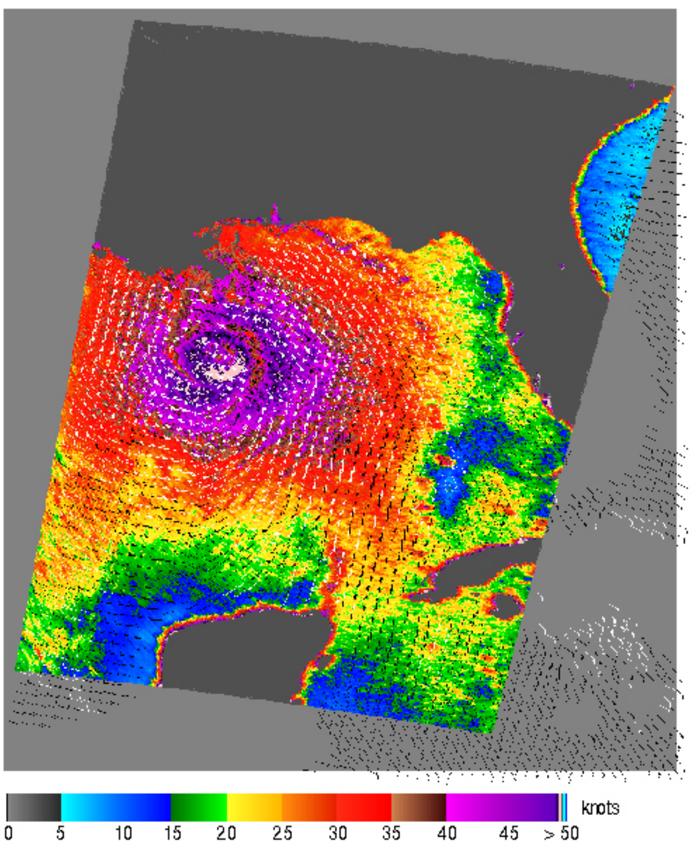


Image of Hurricane Katrina on Sunday, August 28, 2005 at 5:30 PM EDT (21:33 UTC) as seen by the Tropical Rainfall Measuring Mission (TRMM) satellite's precipitation radar, VIRS (Visible Infrared Scanner), TMI (Tropical Microwave Imager), and the GOES spacecraft. TRMM looks underneath the storm's clouds to reveal the underlying rain structure. Blue represents areas with at least 0.25 inches of rain per hour. Green shows at least 0.5 inches of rain per hour. Yellow is at least 1.0 inches of rain per hour, and red is at least 2.0 inches of rain per hour. Credit: NASA/JAXA



This image depicts a 3-day average of actual sea surface temperatures (SSTs) for the Caribbean Sea and the Atlantic Ocean, from August 25-27, 2005. Every area in yellow, orange or red represents 82 degrees Fahrenheit or above. A hurricane needs SSTs at 82 degrees or warmer to strengthen. The data came from the Advanced Microwave Scanning Radiometer (AMSR-E) instrument on NASA's Aqua satellite. Credit: NASA/SVS



Katrina's Category 4 hurricane force winds were observed by NASA's QuikSCAT satellite on August 29, 2005, just before she made landfall. The image depicts wind speed in color and wind direction with small barbs. White barbs point to areas of heavy rain. The highest wind speeds, shown in purple, surround the center of the storm. The scatterometer sends pulses of microwave energy through the atmosphere to the ocean surface and measures the energy that bounces back from the wind-roughened surface. The energy of the microwave pulses changes depending on wind speed and direction, giving scientists a way to monitor wind around the world.
Credit: NASA JPL

September 15, 2005

September 7, 2005

The floods that buried up to 80 percent of New Orleans had noticeably subsided by September 15, 2005, when the top image was taken by the Landsat 7 satellite. The progress in draining the city is evident when the September 15th image is compared with an image taken one week earlier. In the lower image, taken by the Landsat 5 satellite on September 7th, dark flood waters cover much of the city. By September 15th, the flood waters had all but disappeared, lingering only in a few sections of the city. The September 7th image does not show the full extent of the flooding. Taken more than a week after the hurricane struck New Orleans, the image shows a flooded city that had already started to drain. Credit: United States Geological Survey Center for Earth Resources Observation & Science (CEROS).

APPENDIX B:
EXECUTIVE COMMITTEE AND PANEL MEMBERS FOR THE
EARTH SCIENCE AND APPLICATIONS FROM SPACE (ESAS):
A COMMUNITY ASSESSMENT AND STRATEGY FOR THE FUTURE

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