NATIONAL PRIORITIES FOR SOLAR AND SPACE PHYSICS RESEARCH AND APPLICATIONS FOR SPACE WEATHER PREDICTION

HEARING

BEFORE THE

SUBCOMMITTEE ON SPACE AND AERONAUTICS

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED TWELFTH CONGRESS

SECOND SESSION

WEDNESDAY, NOVEMBER 28, 2012

Serial No. 112–107

Printed for the use of the Committee on Science, Space, and Technology

Available via the World Wide Web: http://science.house.gov

U.S. GOVERNMENT PRINTING OFFICE

77–037PDF WASHINGTON : 2012

For sale by the Superintendent of Documents, U.S. Government Printing Office
Internet: bookstore.gpo.gov Phone: toll free (866) 512–1800; DC area (202) 512–1800
Fax: (202) 512–2104 Mail: Stop IDCC, Washington, DC 20402–0001

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HON. RALPH M. HALL, Texas, *Chair*

F. JAMES SENSENBRENNER, JR., Wisconsin
LAMAR S. SMITH, Texas
DANA ROHRABACHER, California
ROSCOE G. BARTLETT, Maryland
FRANK D. LUCAS, Oklahoma
JUDY BIGGERT, Illinois
W. TODD AKIN, Missouri
RANDY NEUGEBAUER, Texas
MICHAEL T. McCAUL, Texas
PAUL C. BROUN, Georgia
SANDY ADAMS, Florida
BENJAMIN QUAYLE, Arizona
CHARLES J. "CHUCK" FLEISCHMANN, Tennessee
E. SCOTT RIGELL, Virginia
STEVEN M. PALAZZO, Mississippi
MO BROOKS, Alabama
ANDY HARRIS, Maryland
RANDY HULTGREN, Illinois
CHIP CRAVAACK, Minnesota
LARRY BUCSHON, Indiana
DAN BENISHEK, Michigan
VACANCY

EDDIE BERNICE JOHNSON, Texas
JERRY F. COSTELLO, Illinois
LYNN C. WOOLSEY, California
ZOE LOFGREN, California
BRAD MILLER, North Carolina
DANIEL LIPINSKI, Illinois
DONNA F. EDWARDS, Maryland
BEN R. LUJÁN, New Mexico
PAUL D. TONKO, New York
JERRY McNERNEY, California
TERRI A. SEWELL, Alabama
FREDERICA S. WILSON, Florida
HANSEN CLARKE, Michigan
SUZANNE BONAMICI, Oregon
VACANCY
VACANCY
VACANCY

SUBCOMMITTEE ON SPACE AND AERONAUTICS

HON. STEVEN M. PALAZZO, Mississippi, *Chair*

F. JAMES SENSENBRENNER JR., Wisconsin
LAMAR S. SMITH, Texas
DANA ROHRABACHER, California
FRANK D. LUCAS, Oklahoma
W. TODD AKIN, Missouri
MICHAEL T. McCAUL, Texas
SANDY ADAMS, Florida
E. SCOTT RIGELL, Virginia
MO BROOKS, Alabama
RALPH M. HALL, Texas

JERRY F. COSTELLO, Illinois
TERRI A. SEWELL, Alabama
DONNA F. EDWARDS, Maryland
FREDERICA S. WILSON, Florida
HANSEN CLARKE, Michigan

EDDIE BERNICE JOHNSON, Texas

CONTENTS

Wednesday, November 28, 2012

NATIONAL PRIORITIES FOR SOLAR AND SPACE PHYSICS RESEARCH AND APPLICATIONS FOR SPACE WEATHER PREDICTION

WEDNESDAY, NOVEMBER 28, 2012

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

The Subcommittee met, pursuant to call, at 10:03 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Steven Palazzo [Chairman of the Subcommittee] presiding.

RALPH M. HALL, TEXAS
CHAIRMAN

EDDIE BERNICE JOHNSON, TEXAS
RANKING MEMBER

U.S. HOUSE OF REPRESENTATIVES

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

2321 RAYBURN HOUSE OFFICE BUILDING
WASHINGTON, DC 20515-6301
(202) 225-6371
www.science.house.gov

Committee on Science, Space, and Technology
Subcommittee on Space and Aeronautics

National Priorities for Solar and Space Physics Research and Applications for Space Weather Prediction

Wednesday, November 28, 2012
10:00 a.m.-12:00 p.m.
2318 Rayburn House Office Building

Witnesses

Dr. Daniel Baker, Director, Laboratory for Atmospheric and Space Physics and Professor, Astrophysical and Planetary Sciences, University of Colorado at Boulder; Chair, Decadal Survey in Solar and Space Physics, National Research Council

Mr. Charles J. Gay, Deputy Associate Administrator, Science Mission Directorate, National Aeronautics and Space Administration

Ms. Laura Furgione, Acting Assistant Administrator for Weather Services and Acting Director, National Weather Service, National Oceanic and Atmospheric Administration

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

National Priorities for Solar and Space Physics Research and Applications for Space Weather Prediction

10 a.m. – 12 p.m.
Wednesday, November 28, 2012
2318 Rayburn House Office Building

Introduction

From the life-giving warmth of heat and energy, to its protective shield from cosmic rays afar, the Sun allows for life to flourish on Earth. Yet in an instant, variations in the Sun's radiation can cause immeasurable damage to our technological way of life.

The study of solar and space physics helps us understand the interactions within the Earth-Sun system. Building our knowledge in this field is essential for maintaining our technological infrastructure and for the prospects of human exploration beyond the protection of Earth's atmosphere and magnetosphere.

The purpose of this hearing will be to examine the recommendations as laid out in the recently released National Research Council's survey on *Solar and Space Physics: A Science for a Technological Society*. Specifically, this hearing will examine the requirements for a robust space-based solar and space physics research program and discuss the application of this research to an operational space weather program.

Witnesses

- **Dr. Daniel Baker,** Director, Laboratory for Atmospheric and Space Physics and Professor, Astrophysical and Planetary Sciences, University of Colorado at Boulder; Chair, Decadal Survey in Solar and Space Physics, National Research Council
- **Mr. Charles J. Gay,** Deputy Associate Administrator, Science Mission Directorate, National Aeronautics and Space Administration
- **Ms. Laura Furgione,** Acting Assistant Administrator for Weather Services and Acting Director, National Weather Service, National Oceanic and Atmospheric Administration

Over-Arching Questions and Issues

- What are the survey committee's top recommendations for the coming decade? What is the current state of the solar and space physics programs at NASA and what are the prospects for the foreseeable future to follow the Decadal Survey's recommendations given that budgets will remain essentially flat?
- What is the role of the Space Weather Prediction Center at NOAA? To what extent does NOAA work with NASA to develop and disseminate space weather models and forecasts? Where can coordination between agencies improve?

- The Decadal Survey highlights the need for a multi-agency partnership to ensure continuity of solar wind observations and "finds the existing ad hoc approach towards the provision of these capabilities" inadequate. Likewise, the survey concluded that "a national, multifaceted program of both observations and modeling is needed to transition research into operations more effectively." What steps, if any, should federal agencies take to ensure a coordinated solar and space physics program is effectively maintained and improved?

Background

Space and solar physics, also known as heliophysics, explores the Sun's connection with – and effects on – the solar system to better understand the Earth and Sun as an integrated system, to protect technologies at Earth, and to enable astronauts to safely live and work in space. As explained by the NRC decadal survey for solar and space physics:

> The research elements of solar and space physics span solar electromagnetic and radiative processes, the generation of solar magnetic fields, the solar wind and interplanetary magnetic fields, their evolution and development and their interaction with planets and moons that have their own magnetospheres and atmospheres. . . Moreover, as human exploration extends further into space – both by means of robotic probes and human spaceflight – and as society's technological infrastructure is linked increasingly to space-based assets and impacted by the dynamics of the space environment, the need to characterize, understand, and predict the dynamics of our environment in space becomes ever more pressing.[1]

The Sun-Earth system is collectively studied by a system of observatories supported by NASA and the National Science Foundation (NSF) and augmented by DOD, National Oceanic and Atmospheric Administration (NOAA) and international partners known as the Heliophysics System Observatory (HSO). Figure 1 depicts the HSO, which consists of 18 space-based operating missions ranging from the Voyager probes launched over 30 years ago to the Radiation Belt Storm Probes (recently renamed the Van Allen probes) launched in August 2012. As an integrated set of observing platforms, the HSO gives researchers a "big-picture" viewpoint of the space environment under the Sun's influence. *(See Appendix 1 for a short description of each mission)*

[1] Solar and Space Physics: A Science for a Technological Society, National Academies Press, Washington, D.C. August 2012, pre-publication version, pg. 1-5

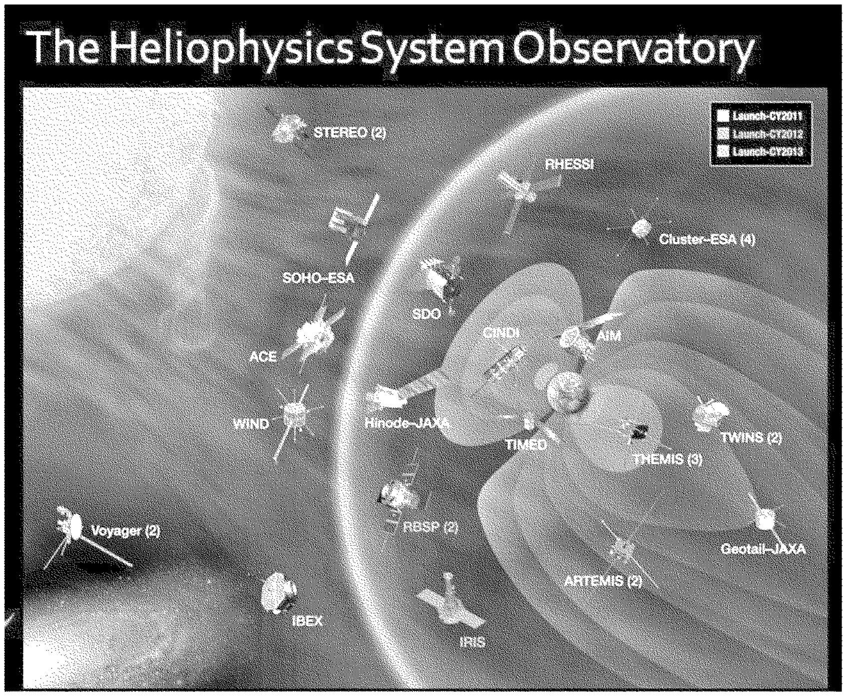


Figure 1. Source – National Research Council

There are currently several missions in the development phase or nearing the development phase that will augment the HSO in the near future:

- The **Interface Region Imaging Spectrograph (IRIS)**, expected to launch in June 2013, will observe changes just above the solar surface to help explain the origin on heat and mass fluxes of the solar corona and wind.
- The **Magnetospheric Multiscale Mission (MMS)**, expected to launch in March 2015, will assess the magnetic reconnection of ions within Earth's magnetic field.
- **Solar Orbiter**, in collaboration with the European Space Agency, is due to launch in 2017 and will examine the connection between the regions of the sun.
- **Solar Probe Plus (SPP)**, expected to launch in 2018, will explore the previously unexplored solar corona to see how it is heated and how the solar wind is accelerated to high energies.

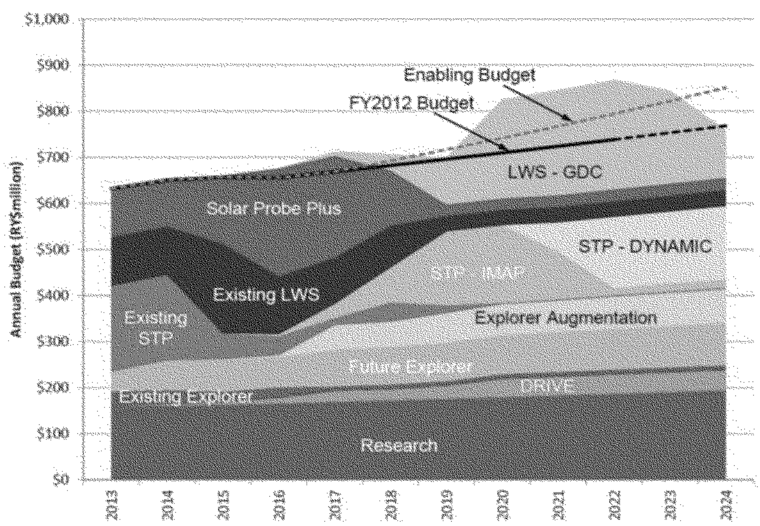
Additionally, the HSO is supported by a system of ground-based observatories and related analysis managed by the National Science Foundation. (A more complete description of the NSF network is described in a section below.)

The seemingly robust HSO, however, is very delicate as many satellites and ground-based support networks are operating beyond their intended lifetimes. Many outside factors – including launch costs and frequency – are contributing to a less-than-certain future for the HSO architecture. As the survey report maintains:

> An already lean solar and space physics program is also threatened by the prospect of level or even declining budgets for the foreseeable future. The rising cost of executing space missions only exacerbates this problem, and the resultant shortfalls affect both programs and, indirectly, the "pipeline" of future engineers and scientists who choose to enter the field. In the coming years, the solar and space physics enterprise will be challenged by demands to maintain and expand the breadth of its system-level observatory to meet the needs of a space-faring nation.[2]

Recommendations for the Next Decade

The traditional role of a decadal survey committee is to recommend a set of new scientific targets for a particular discipline deemed by its related community as the highest priority research to conduct for the coming decade. Acknowledging the limited resources in the foreseeable future, this survey committee partly broke away from this tradition in that it recommends implementing already selected missions while supporting enabling activities to ensure a robust program now and in the future. Additional suggestions are offered should the budget be augmented in the future, but these increased funds are not assumed in the baseline prioritization of activities. Figure 2 provides a sand chart of the current and recommended heliophysics program at NASA. The recommended program is described below.



[2] Solar and Space Physics, pg. 1-5.

Figure 2: Source National Research Council

The top recommendation for NASA, therefore, is to complete the current set of selected missions on time and on schedule. Specifically, the decadal committee recommends rigorous oversight of the upcoming Solar Probe Plus mission as critical to the program's success in the coming decade.

The second priority for NASA should be the effective utilization of their scientific assets through an initiative dubbed DRIVE (Diversify, Realize, Integrate, Venture, Educate). The tenets of the DRIVE initiative are founded on the use of a broad set of observing platforms, a greater emphasis on data analysis, strengthening ties between agency disciplines, development of technologies and instruments, and a focus on the next generation of space researchers through education outreach and participatory programs.

Specifically, NASA should focus its Explorer missions to allow for continued research and technology development without a large outlay of funds. An additional $70 million per year would restore the option of Mid-size Explorer (MIDEX) missions and allow them to be offered alternately with Small Explorer (SMEX) missions at a cadence of one every 2-3 years. According to the committee, the strength of this program is its ability "to respond rapidly to new concepts and developments in science. . . The Explorer mission line has proven to be an outstanding success, delivering – cost effectively – science results of great consequence."[3] Such an augmentation would also allow for more regular selections of Missions of Opportunity (MOOs).

The next priority area the committee recommends would be to restructure the Solar-Terrestrial Probes (STP) program as a moderate-sized, principal investigator-led (PI-led) mission line cost capped at $520 million (including full lifecycle costs). The committee points to the success of the Planetary Science Division's Discovery and New Frontiers programs that have yielded missions delivered on time and within budget. Managing STP similarly through a competed, cost-capped mission with PI's who are empowered to make design trade-offs necessary to remain within the cost cap would enable a well-rounded program that is balanced by the larger-scale, NASA center-led Living with a Star (LWS) missions and the smaller-class Explorer missions.

Even though the decadal committee recommended that STP be a competed mission line, they still recommend a set of science targets with associated reference missions as a guide. In order of importance, the committee recommends STP pursue the following:

1. The **Interstellar Mapping and Acceleration Probe (IMAP)** would seek to understand the outer heliosphere and its interaction with the interstellar medium as well as measure solar wind inputs. IMAP should be implemented first in order to ensure complementary measurements with the Voyager missions. *This mission would be critical for maintaining a continuous solar wind measurement needed for accurate space weather prediction.*
2. The **Dynamical Neutral Atmosphere-Ionosphere Coupling (DYNAMIC)** reference mission would provide scientists with a comprehensive understanding of the variability in space weather driven by lower atmosphere weather on Earth.
3. The **Magnetosphere Energetics, Dynamics, and Ionospheric Coupling Investigation (MEDICI)** reference mission would seek to determine how the magnetosphere-ionosphere-thermosphere system is coupled and how it responds to solar and magnetospheric forcing.

[3]Solar and Space Physics, pg. S-6

Finally, the committee concluded that the Living with a Star (LWS) mission line at NASA is appropriately pursuing large and complex scientific problems and should continue to be managed and executed by NASA centers. In addition to flight programs, LWS supports research technology development, strategic capabilities and education programs. The next major LWS mission NASA should pursue is a study of the ionosphere-thermosphere-mesosphere system in an integrated fashion. The survey committee recommends the **Geospace Dynamics Constellation (GDC)** reference mission that would focus on how the Earth's atmosphere absorbs solar wind energy. Given anticipated budgets, however, the committee does not recommend starting this program until the Radiation Belt Storm Probes (Van Allen Probes) and Solar Probe Plus are completed and launched (RBSP was launched August 2012 and SPP is due for launch in 2018). The earliest GDC could be launched is 2024, 6 years after SPP. The survey committee warns that this should be the absolute minimum cadence between major missions.

In light of the uncertainty about the future of federal funding, the survey committee produced a set of "decision rules" meant to guide NASA should the budget remain flat or decline. Top on the list is a reduction in scope or delay development for both STP and LWS missions. Specifically, the report provides explicit triggers for NASA to review the Solar Probe Plus mission to ensure cost and/or program balance is contained. The next step would be for NASA to scale back the recommended increase in cadence of the Explorer missions. And finally, should further reductions be needed, the survey committee recommends delaying the profile outlined in the DRIVE initiation and at a minimum ensure the NASA research elements be maintained.

Importance of Understanding Solar and Space Physics

The adverse effects of space weather on modern technology weighed heavily on the decadal survey as they framed their recommendations for the coming decade. Their intent was aimed at achieving scientific results that would be most useful to society.

The United States is increasingly reliant on our satellite infrastructure. For example, satellites are integral to civilian and military communications and the Global Positioning Satellites (GPS) enable everyday activities such as navigation and financial transactions. Yet those assets are subject to the conditions of the space environment within which they operate. Furthermore, human space exploration and the electric power grid are both dependent on accurate and timely notification of significant space weather events. Figure 3 demonstrates the types of solar activity that are of concern and their effects on our human infrastructure.

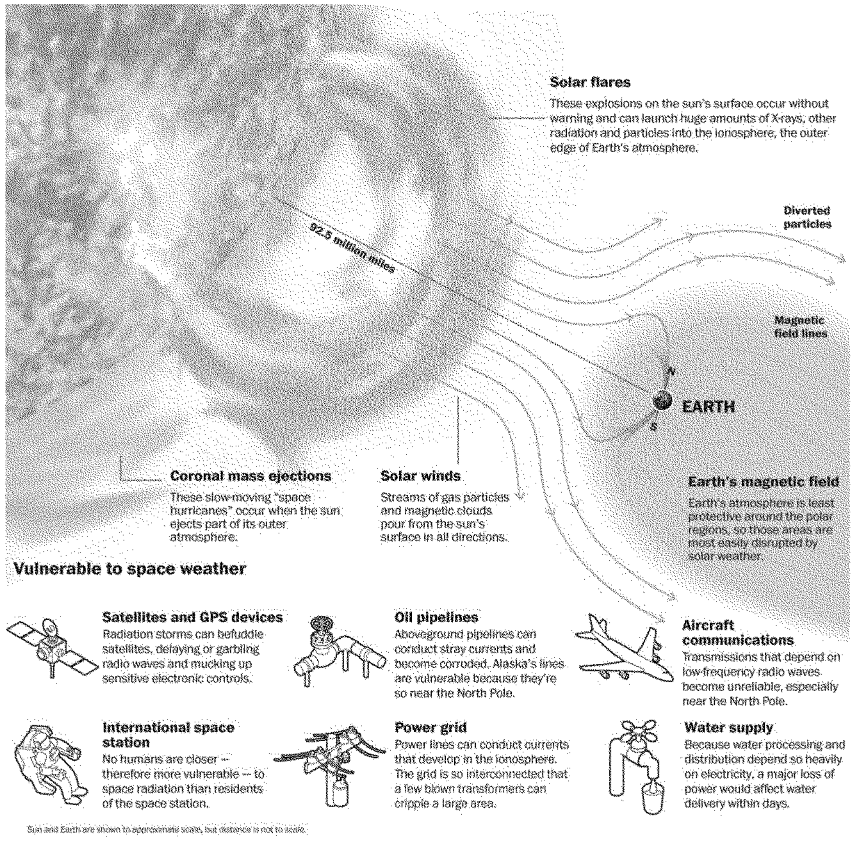


Figure 3: NASA. Bonnie Berkowitz And Alberto Cuadra / The Washington Post. Published on January 23, 2012

Space Weather Prediction

The NOAA Space Weather Prediction Center (SWPC) is the primary provider of space weather services to civilian users. According to the SWPC website:

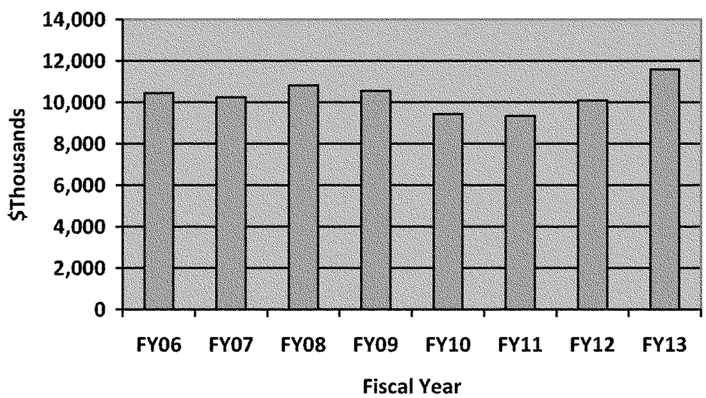
> *The Space Weather Prediction Center (SWPC) is part of the National Weather Service and is one of the nine National Centers for Environmental Prediction. It is the nation's official source of space weather alerts, watches and warnings. SWPC provides real-time monitoring and forecasting of solar and geophysical events, which impact satellites, power grids, communications, navigation, and many other technological systems. SWPC also explores and evaluates new models and products and transitions them into operations. SWPC is also the primary warning center for*

the International Space Environment Service and works with many national and international partners with whom data, products, and services are shared.[4]

NASA's Advanced Composition Explorer (ACE), NOAA's Geostationary Operational Environmental Satellites (GOES) and Polar Operational Environmental Satellites (POES), magnetometers, and the U.S. Air Force's solar observing networks are the primary source of information about solar activity. SWPC draws on these data sources to provide relevant and timely information to civilian and commercial users. Additional information is drawn from other NASA research satellites (such as Solar and Heliophysics Observatory (SOHO) and the Solar Terrestrial Relations Observatory (STEREO)) and ground-based facilities managed by NSF.

By utilizing both ground- and space-based observations to assess the current state of the space environment, space weather forecasters analyze current conditions, compare these to historical data, and using numerical models (similar to those used to predict weather), they are able to predict space weather. SWPC uses this information to generate forecasts and issue alerts to subscribers. Since the subscription service began in January 2005, the number of customers has grown exponentially. In 2012, the number of subscribers jumped to over 24,000. Examples of customers range from satellite operators, airline companies and manufacturers, state departments of transportation, electric utility companies, and other federal agencies.

NOAA Space Weather Prediction Center – Annual Enacted Budget (FY13-*Requested*)



Transitioning Research to Operations

Despite a primary focus on research missions, NASA's science missions have routinely been utilized for operational purposes. These missions provide critical measurements for characterizing and forecasting the space environment, yet there is no standard process for transitioning research into operations. The decadal survey committee found the current approach to be inadequate and provides several recommendations aimed at ensuring

[4] http://www.swpc.noaa.gov/AboutUs/index.html

continuity of critical measurements and future development. Central to these recommendations is a vision for a national Space Weather and Climatology Program.

In order to develop this new program, the survey committee recommends re-chartering the National Space Weather Program through the National Science and Technology Council, including participation from the Office of Science and Technology Policy and the Office of Management and Budget. NOAA's Office of the Federal Coordinator for Meteorological Services and Supporting Research currently administers the National Space Weather Program. The survey committee notes that the charter for the National Space Weather Program dates back to 1995 and that re-chartering it at a higher level in government would provide the necessary program oversight and resources that is needed to coordinate across agency roles and responsibilities.

Additionally, NASA, NOAA and DOD should work together to ensure continuity of solar and solar wind observations beyond the lifetimes of the current systems. In the short-term NASA, under contract from NOAA, is refurbishing an existing NASA satellite with solar wind sensors known as the Deep Space Climate Observatory (DSCOVR). The refurbished satellite is slated to launch in 2014 and has a design life of 2 years (though NOAA is planning for a 5 year mission). The survey committee recommended IMAP design reference mission (described above) would also fulfill the needed measurements in the nearer-term, but the committee stresses the importance of planning for uninterrupted measurements in the future. *It is also important to note that key measurements now made by the POES and DOD spacecraft are not currently part of the next generation of Earth observing weather satellites.*

The survey committee also recommends:

- A community-wide assessment of new observations, platforms and locations that could improve space weather services including dissemination of space weather alerts.
- NOAA should establish a space weather research program to transition research to operations.
- Distinct funding lines for basic space physics research and for space weather specification and forecasting should be developed and maintained.

2010 NASA Authorization Report on Space Weather

Acknowledging the significant threat space weather has on modern technological systems, Section 809 of the 2010 NASA Authorization bill (PL 111-267) directs the Office of Science and Technology Policy (OSTP) to submit a report within 180 days of enactment that details both the current space- and ground-based assets necessary for space weather forecasting and the systems needed to gather data for the next decade. As of November 20, 2012 the report has not been delivered to Congress.

Solar and Space Physics at the National Science Foundation

The global nature of solar and space physics necessitates an observational approach that is both space- and ground- based. NASA's existing heliophysics flight missions and NSF's ground-based facilities form a network of observing platforms that operate in unison to investigate the solar system. For NSF, the previous decade witnessed the initial deployment of the Advanced Modular Incoherent Scatter Radar (AMISR) in Alaska. It is a mobile facility used to study the upper atmosphere and to observe space weather events. Also, the initial development of the Advanced Technology Solar Telescope (ATST), a 4 meter-aperture optical solar telescope due to begin operations in 2018, will provide the most highly resolved measurements ever obtained of the Sun's plasma and magnetic field. These new NSF facilities join a broad range of existing ground-based assets that provide an essential global synoptic perspective and complement space-based measurements of the solar and space physics system.

The main priority for NSF according to the survey committee, therefore, is to support existing ground-based facilities and to complete those nearing final stages of implementation. This includes maintaining and developing systems for accessing, archiving and mining synoptic and long-term datasets.

Additionally, the survey committee recommends that NSF start-up a new mid-scale funding line. The NSF Committee on Programs and Plans recently formed a task force to study how effectively it supports mid-scale projects. The committee deliberations and panel studies revealed a variety of important projects that would benefit from a mid-scale funding line. The committee cites multiple projects as high-value candidates ranging from telescopes designed to detect and image radio emissions to observatories capable of measuring solar eruptive events, wind and temperature, gravity waves, and atmospheric disturbances. Furthermore, support for continuing instrumentation and technology development in both national facilities and in our universities is important to ensure young scientists and engineers in the field are nurtured.[5]

The survey committee also highlights the tremendous potential the CubeSats program as a unique platform for technological innovation and at a cost accessible to university students. The work by NSF Atmospheric and Geospace Sciences Division to support student CubeSats has been enormously successful and as of October 2011, eight Cubesat programs have been initiated. The committee recommends creating a new funding line dedicated to CubeSats and increasing the program from $1.5 million to $2.5 million annually.

Faculty and curriculum development and undergraduate and graduate training is essential for cultivating the next generation of solar and space physicists and the survey committee endorses continuing programs at the NSF that encourage such development. Likewise, the cross-cutting nature of these disciplines requires an approach that reaches across disciplines and international boundaries, and the survey committee recommends promoting a more unified, multi-disciplinary approach to the study of solar and space physics within NSF.

[5] Solar and Space Physics, p. 5-2 – 5-4

Appendix 1 – HSO Mission Overview
(Adopted from NASA Sources)

Voyager – After operating for over 34 years, Voyager 1 and 2 are approaching the edge of our solar system. The current mission objective, Voyager Interstellar Mission (VIM), is characterizing the heliopause boundary where the Sun's magnetic field and solar wind is being slowed by the pressure of interstellar gas outside the Sun's influence.

Geotail – Launched in July 1992, the GEOTAIL spacecraft was designed to study the dynamics of the Earth's magnetotail over a wide range of distance, extending from the near-Earth region to the distant tail.

Wind – The task of Wind is to measure crucial properties of the solar wind before it impacts the Earth's magnetic field and alters the Earth's space environment (which contains charged particles, electric and magnetic fields, electric currents and radiation) and upper atmosphere in a direct manner. Wind was launched in November 1994.

SOHO – The Solar and Heliophysics Observatory, launched in December 1995, is a ESA and NASA mission to study the Sun from its interior, through the hot and dynamic atmosphere, to the solar wind and its interaction with the interstellar medium. Together with two other ESA missions, Cluster and Ulysses, SOHO is studying the Sun-Earth interaction from different perspectives.

ACE – The Advanced Composition Explorer provides near-real-time solar wind information over short time periods, providing an advance warning of geomagnetic storms that can overload power grids, disrupt communications on Earth, and present a hazard to astronauts. ACE was launched in August 1997.

Cluster II – Launched in July 2000, Cluster is a constellation of four identical spacecraft that simultaneously measure the interactions between Earth's magnetosphere and the solar wind.

TIMED – The Thermosphere, Ionosphere, Mesosphere Energetics and Dynamics mission seeks to understand the energy transfer into and out of the Mesosphere and Lower Thermosphere/Ionosphere (MLTI) region of the Earth's atmosphere – one of the least understood regions in the Earth's atmosphere and one that is sensitive to both effects from the Sun and Earth's atmosphere below. TIMED launched in December 2001.

RHESSI – Reuven Ramaty High Energy Solar Spectroscope Imager was launched in February 2005. The goal of the mission was to combine high-resolution imaging in hard X-rays and gamma rays with high-resolution spectroscopy, to find out where these particles are accelerated and to what energies. Such information will advance understanding of the fundamental high-energy processes at the core of the solar flare problem.

TWINS A &B – Two Wide-Angle Imaging Neutral-Atom Spectrometers launched in March 2008 that utilize two identical instruments on two widely spaced spacecraft to enable the 3-dimensional visualization and the resolution of large scale structures and dynamics within the magnetosphere.

Hinode- Led by the Japanese Space Agency (JAXA) and launched in September 2006, Hinode (also known as Solar-B) consists of three telescopes that investigate the role of magnetic fields as drivers of solar eruptions. (Hinode is Japanese for sunset and is a companion mission to Solar-A known as Yohkoh).

STEREO – The Solar Terrestrial Relations Observatory consists of two nearly identical spacecraft - one ahead of Earth in its orbit, the other trailing behind, offering a unique perspective that enables a 3-D side-view of coronal mass ejections. These observations provide alerts for Earth-directed solar ejections. These spacecraft were launched in October 2006.

THEMIS - Time History of Events and Macroscale Interactions during Substorms was launched in February 2007 and employs 5 identically-instrumented spacecraft in orbits whose apogees line up once every 4 days over a dedicated array of ground observatories located in Canada and the northern United States. The spacecraft and ground observations enable researchers to pinpoint when and where substorms begin. THEMIS will complement MMS (still in development) and serves as a science and a technology pathfinder for future STP missions. The two outermost probes were repurposed in 2010 (after the initial science mission of THEMIS) and renamed ***ARTEMIS*** and are currently in lunar orbit studying the moon's interior and surface composition.

AIM – Aeronomy of Ice in the Mesosphere studies unique clouds high in the Earth's atmosphere known as Polar Mesospheric Clouds (PMCs). Unlike the more common clouds, PMC's can only be seen near twilight. They usually form only at high latitudes near the North and South Poles. In recent years, however, these clouds are being seen at lower latitudes more frequently and scientists are interested to see if they are related to climate change. AIM was launched in April 2007.

CINDI – The Coupled Ion-Neutral Dynamics Investigations seeks to understand the interaction between electrically neutral and electrically charged gases in the upper atmosphere. This mission, launched in April 2008, provides two instruments for the Communication/Navigation Outage Forecast System (C/NOFS) satellite, a United States Air Force (USAF) project, to help predict the behavior of irregularities which can cause major problems for communications and navigation systems.

IBEX- Interstellar Boundary Explorer measures particles called energetic neutral atoms (ENAs) which are particles that have no charge and move very quickly. These particles are a result from a collision of material between the stars – called interstellar medium – with the solar wind that flows outward well beyond the orbits of the planets. IBEX contains two detectors designed to collect and measure ENAs and provide scientists with data about the mass, location, direction of origin and the energy of these particles. From this data, maps of the interstellar boundary are derived. IBEX was launched in October 2008.

SDO – The Solar Dynamics Observatory (SDO), launched February 2010, is the cornerstone of a NASA's Living With a Star (LWS) Program. The program is meant to develop the scientific understanding necessary to address those aspects of the sun and solar system that directly affect life and society. SDO will study how solar activity is created and how space weather results from that activity by measuring the sun's interior, magnetic field, the hot plasma of the solar corona, and the solar irradiance.

The Subcommittee met, pursuant to call, at 10:03 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Steven Palazzo [Chairman of the Subcommittee] presiding.

Chairman PALAZZO. The Subcommittee on Space and Aeronautics will come to order.

Good morning, and welcome to today's hearing entitled "National Priorities for Solar and Space Physics Research and Applications for Space Weather Prediction." In front of you are packets containing the written testimony, biographies and Truth in Testimony disclosures for today's witness panel. I recognize myself for five minutes for an opening statement.

I would like to begin by thanking our witnesses for taking time from their busy schedules to appear before us this morning to examine the National Research Council's recommendations for the U.S. solar and space physics research program and applications for space weather prediction. I realize you and your staff devoted considerable time and effort preparing for this hearing, and we appreciate your expertise as we consider these issues in the upcoming session of Congress.

Unfortunately, our Ranking Member was unable to join us today, but before getting started, I did want to extend my warm wishes to Subcommittee Ranking Member Jerry Costello, who is retiring at the end of this Congress. He has been a genuine pleasure to work with, and in the brief time we have served together, I have come to admire his deep knowledge about this institution, NASA, his deep insight into the FAA, and his sense of grace. He has been a steady voice of reason, and I believe we will all miss him.

Our hearing today will focus on the incredible work being accomplished by NASA's Heliophysics Division and on the important operational aspect this research has for space weather prediction at NOAA. NASA has developed and launched a broad network of spacecraft that allows researchers to better understand the Earth-Sun system. Their findings are used daily to help preserve our technological infrastructure by allowing system operators to better react to variations of the Sun. Building our knowledge in this field is essential for maintaining our way of life on Earth as well as for improving the capability of enabling human exploration beyond the protection of Earth's atmosphere and magnetosphere. Together with a ground-based infrastructure of solar telescopes managed by the National Science Foundation, NASA and NOAA coordinate critical measurements into useable models that predict how space weather will affect our satellites, electric power grid, airline operators, and more. The Space Weather Prediction Center, operated by NOAA's National Weather Service, provides real-time monitoring and forecasting of solar and geophysical events and is continuously exploring new models and products to transition to operations.

Today's hearing will examine the requirements for a robust space-based solar and space physics research program and discuss the application of this research for an operational space weather program. The baseline assessment in this examination will be the set of recommendations outlined by the National Research Council's Solar and Space Physics: A Science for a Technological Society decadal survey. Notably, the survey committee acknowledged the prospect of limited budgets and therefore recommended NASA stay the course on major programs under development, specifically for Solar Probe Plus. The survey committee further recommended that NASA utilize its current resources most effectively by focusing resources on those activities that will DRIVE; or Diversify, Realize, Integrate, Venture Educate, the next generation of solar and space physics research. The survey committee also provides specific recommendations for our Nation's space weather enterprise and provides detailed recommendations to NASA, NSF and NOAA on how to best accomplish a robust space weather and climatology program for the future.

As we enter into the next solar maximum—an 11-year solar cycle that is marked by increased solar activity—the availability of solar wind measurements in particular are essential for maintaining our way of life. As has been stated countless times over the last several years, however, we face a tough budget environment. In order to continue a robust solar and space physics program, a prudent and careful examination of the core capabilities and essential services this country needs is first and foremost on our agenda.

I look forward to today's discussion, and wish to again thank our witnesses for their presence.

[The prepared statement of Mr. Palazzo follows:]

PREPARED STATEMENT OF SUBCOMMITTEE CHAIRMAN STEVEN M. PALAZZO

I would like to begin by thanking our witnesses for taking time from their busy schedules to appear before us this morning to examine the National Research Council's recommendations for the U.S. solar and space physics research program and applications for space weather prediction. I realize you and your staff devoted considerable time and effort preparing for this hearing and we appreciate your expertise as we consider these issues in the upcoming session of Congress.

Our hearing today will focus on the incredible work being accomplished by NASA's Heliophysics Division and on the important operational aspect this research has for space weather prediction at NOAA. NASA has developed and launched a broad network of spacecraft that allow researchers to better understand the Earth-Sun system. Their findings are used daily to help preserve our technological infrastructure by allowing system operators to better react to variations of the Sun. Building our knowledge in this field is essential for maintaining our way of life on Earth as well as for the improving the capability of enabling human exploration beyond the protection of Earth's atmosphere and magnetosphere.

Together with a ground-based infrastructure of solar telescopes managed by the National Science Foundation, NASA and NOAA coordinate critical measurements into useable models that predict how space weather will affect our satellites, electric power grid, airline operators, and more. The Space Weather Prediction Center operated by NOAA's National Weather Service, provides real-time monitoring and forecasting of solar and geophysical events and is continuously exploring new models and products to transition to operations.

Today's hearing will examine the requirements for a robust space-based solar and space physics research program and discuss the application of this research for an operational space weather program. The baseline assessment in this examination will be the set of recommendations outlined by the National Research Council's *Solar and Space Physics: A Science for a Technological Society* decadal survey. Notably, the survey committee acknowledged the prospect of limited budgets and therefore recommended NASA "stay the course" on major programs under development—specifically for Solar Probe Plus. The survey committee further recommended that NASA utilize its current resources most effectively by focusing resources on those activities that will "DRIVE—or Diversify, Realize, Integrate, Venture, Educate" the next generation of solar and space physics research.

The survey committee also provides specific recommendations for our nation's space weather enterprise and provides detailed recommendations to NASA, NSF and NOAA on how to best accomplish a robust space weather and climatology program for the future.

As we enter into the next solar maximum—an 11 year solar cycle that is marked by increased solar activity—the availability of solar wind measurements in particular are essential for maintaining our way of life. As has been stated countless times over the last several years, however, we face a tough budget environment. In order to continue a robust solar and space physics program, a prudent and careful examination of the core capabilities and essential services this country needs is first and foremost on our agenda.

I look forward to today's discussion, and wish to again thank our witnesses for their presence.

Chairman PALAZZO. At this time I now recognize Ms. Edwards for an opening statement.

Ms. EDWARDS. Thank you Chairman Palazzo, and thank you for your gracious comments about Ranking Member Jerry Costello. I know he regrets not being here, and like you, I too have learned both from his graciousness but also from his work ethic.

Mr. Chairman, I appreciate your holding this hearing today to examine the recommendations for the Nation's solar and space physics research program and the benefits of this research for space weather prediction.

A little more than a week ago, the Sun had two solar events, in this case prominence eruptions, over a 4-hour time span. NASA's Solar Dynamic Observatory spacecraft captured the activity, and while the event would not affect Earth, this and other solar events days earlier led to alerts of potential high-frequency radio communication blackouts and weak power grid fluctuations.

Because solar events such as these can have marked impacts on ground- and space-based technological systems and services, such as GPS-related services, communications, aviation, the electric power grid, and pipelines, the Nation's basic research programs have a direct bearing on protecting our Nation's critical infrastructure.

In August 2012, the National Academies released its decadal survey, "Solar and Space Physics: A Science for a Technological Society." The recommendations provided independent, external input on the priorities and plans for space and ground-based solar and space physics research activities over the next decade, and on the applications of the research to space weather prediction.

So, I am pleased to hear from our witnesses today on the decadal survey recommendations, the current activities and future plans for the NASA program, and the operational activities related to space weather prediction. And Mr. Chairman, I would be remiss if I didn't mention the budgetary challenges for this research. In a crunch budget environment, there are significant implications for our society if we don't continue and expand research in this area. We need to protect these R&D investments. Our assets, our quality of life and our economic strength as a Nation depend on the research.

Thank you and I yield back the balance of my time.

[The prepared statement of Ms. Edwards follows:]

PREPARED STATEMENT OF ACTING RANKING MINORITY MEMBER DONNA F. EDWARDS

Mr. Chairman, thank you for holding today's hearing to examine the recommendations for the nation's solar and space physics research program and the benefits of this research for space weather prediction.

A little more than a week ago, the Sun had two solar events-in this case "prominence eruptions"—over a four-hour time span. NASA's Solar Dynamic Observatory

(SDO) spacecraft captured the activity, and while the event would not affect Earth, this and other solar events days earlier led to alerts of potential high frequency radio communication blackouts and weak power grid fluctuations.

Because solar events such as these can have marked impacts on ground- and space-based technological systems and services, such as GPS-related services, communications, aviation, the electric power grid, and pipelines—the Nation's basic research programs have a direct bearing on protecting our nation's critical infrastructure.

In August 2012, the National Academies released its decadal survey, *"Solar and Space Physics: A Science for a Technological Society."*

The recommendations provide independent, external input on the priorities and plans for space- and ground-based solar and space physics research activities over the next decade, and on the applications of the research to space weather prediction.

So, I'm pleased to hear from our witnesses today on the decadal survey recommendations, the current activities and future plans for the NASA program, and the operational activities related to space weather prediction.

Mr. Chairman, I would be remiss if I did not mention the budgetary challenges for this research, which has such significant implications for our society.

We need to protect these R&D investments. Our assets, our quality of life, and our economic strength as a nation depend on this research.

Thank you and I yield back the balance of my time.

Chairman PALAZZO. Thank you, Ms. Edwards.

If there are Members who wish to submit additional opening statements, your statements will be added to the record at this point.

At this time I would like to introduce our panel and then we will proceed to hear from each of them in order.

Our first witness is Dr. Daniel Baker. Dr. Baker is Director of the Laboratory for Atmospheric and Space Physics, University of Colorado at Boulder, and is Professor of Astrophysical and Planetary Sciences and Professor of Physics there. He currently is Lead Investigator on several NASA space missions including the Messenger mission to Mercury, the Magnetosphere Multiscale mission, and the NASA Radiation Belt Storm mission. He was a member of the 2006 decadal review of the U.S. National Space Weather Program and recently chaired the National Research Council's 2013 to 2022 decadal survey in solar and space physics.

Our next witness is Mr. Charles Gay, the Deputy Associate Administrator for the Science Mission Directorate at the National Aeronautics and Space Administration. Mr. Gay has served NASA in senior management positions for many years including Deputy Director of the Office of Systems Safety and Mission Assurance at Goddard Space Flight Center, NASA Deputy Director of the Heliophysics Division at NASA headquarters. In addition to his experience at NASA, Mr. Gay has over 20 years of experience in the aerospace industry. Mr. Gay received a B.S. in civil engineering and an M.S. in structural engineering from the University of Maryland.

Our final witness is Ms. Laura Furgione, who serves as the National Oceanic and Atmospheric Administration Acting Assistant Administrator for Weather Services and Acting Director of the National Weather Service. In this role, she is responsible for the day-to-day civilian weather operations for the United States, its territories, adjacent waters and ocean areas. Ms. Furgione has served NOAA in a variety of roles over her career including the Deputy Director of NWS and as Assistant Administrator for the NOAA Office of Program Planning and Integration. Ms. Furgione holds a bachelor of science degree in Atmospheric Science from the University of Missouri-Columbia and a master's degree in public administration from the University of Alaska Southeast.

Welcome, everyone. And as our witnesses should know, spoken testimony is limited to five minutes each. After all witnesses have spoken, Members of the Committee will have five minutes each to ask questions.

I now recognize our first witness, Dr. Daniel Baker, for five minutes to present his testimony.

STATEMENT OF DR. DANIEL BAKER, DIRECTOR, LABORATORY FOR ATMOSPHERIC AND SPACE PHYSICS, AND PROFESSOR, ASTROPHYSICAL AND PLANETARY SCIENCES, UNIVERSITY OF COLORADO AT BOULDER, AND CHAIR, DECADAL SURVEY IN SOLAR AND SPACE PHYSICS, NATIONAL RESEARCH COUNCIL

Dr. BAKER. Thank you, Mr. Chairman, and thank you, Representative Edwards. Thank you for the opportunity to testify today. My name, as said, is Daniel Baker. I am at the University of Colorado. It was my privilege to chair the National Research Council's Committee for a Decadal Strategy for Solar and Space Physics, or heliophysics, as it is referred to at NASA.

Our study was requested by NASA and the National Science Foundation and was carried out with the full cooperation of these agencies and with NOAA. The study is national in scope, and its recommendations are directed to all relevant agencies engaged in solar and space physics research and applications. I believe that implementation of the survey committee's recommended programs will ensure the United States maintains its leadership in space physics and will lead to significant, even transformative advances in scientific understanding and operational capabilities.

Space physics research provides new observations and scientific knowledge about the Sun and how it interacts with the planets and with the local reaches of our galaxy. Of most importance to society, solar and space physics research observations and modeling lets us understand the origins and consequences of the Sun's interactions with the Earth and what we refer to as space weather.

Our report is one that is responsive to both of these drivers, the necessity to be innovative in the science field with multi-agency, multi-scale observations and theoretical tools, and a community that seeks to add value to a Nation that is increasingly vulnerable to space weather effects.

The decadal survey committee's recommendations are also responsive to budgetary constraints. Recognizing the importance of crafting a resilient program in uncertain budgetary times, the survey report includes decision rules to guide programmatic changes should they become necessary.

NASA's existing heliophysics flight missions and NSF's ground-based facilities form a network of observing platforms that operate simultaneously to investigate the entire solar system. The survey's first priority is to complete the ongoing program, to support this ongoing existing program and complete missions and programs in development.

Our second-highest priority is to implement a new, integrated, multi-agency initiative, which we call D–R–I–V–E, as was said, DRIVE, encompasses specific cost-effective augmentations to NASA and NSF's space physics programs. DRIVE will bring existing enabling programs to full fruition through innovative, targeted programs and will also support larger-scale activities recommended for later in the decade. Its components are described more thoroughly in my written testimony.

Our third priority is for NASA to accelerate and expand the Heliophysics Explorer program. Explorer-class missions have an outstanding record of delivering scientific results of great consequence in a timely and cost-effective manner.

The fourth priority is that the committee also recommends that NASA's Solar-Terrestrial Probes program should be restructured as a moderate-sized competed principal investigator-led mission line that is cost-capped at $520 million per mission, full lifecycle cost. The first recommended new solar-terrestrial probe reference target, IMAP, is to capitalize on Voyager observations to understand the outer heliosphere and its interactions with the inner stellar medium. Certain landmark scientific problems are of such scope and complexity, they can only be addressed with major missions. In our survey committee plan, major heliophysics missions would be implemented within NASA's Living With a Star (LWS) program. The survey committee recommends that they continue to be managed and executed by NASA centers.

As this Committee knows full well, multiple agencies in the Federal Government have vital interests related to space weather. Our committee is concerned about the degree of coordination between these agencies and the ad hoc nature of partnerships and the limited nature of resources. For reasons detailed in our report, our committee believes the first necessary but insufficient step is to recharter the existing space weather coordinating body, the National Space Weather Program, under the auspices of the National Science and Technology Council. Rechartering in this way may improve interagency coordination but longer-term, additional resources will be necessary to ensure continuing availability of the requisite measurements. NASA research satellites such as ACE, SOHO, STEREO, SDO, which are designed for scientific studies, provide critical measurements essentially for specifying and forecasting space environment systems. However, NASA has neither the mandate nor the budget to sustain these measurements into the future.

In the survey report, the committee articulates a vision for an enhanced national commitment by partnering agencies—NOAA, NASA, NSF, USGS, other agencies—for continued measurements of critical space environment parameters. In this partnership, we see NASA utilizing its unique space-based capabilities as the basis for a new program that provides sustained monitoring of key space environment observables.

Thank you again for the opportunity to bring these issues from the NRC decadal survey to your attention. I look forward to your questions. Thank you very much.

[The prepared statement of Dr. Baker follows:]

Statement of Daniel N. Baker
Broad Reach Endowed Chair of Space Sciences
Professor, Department of Physics and Department of Astrophysical and Planetary Sciences
Director, Laboratory for Atmospheric and Space Physics
University of Colorado, Boulder

Before the Subcommittee on Space and Aeronautics
Committee on Science, Space, and Technology
U.S. House of Representatives

November 28, 2012

Mr. Chairman, Ranking Minority member, and members of the Committee, I want to thank you for the opportunity to testify today at the hearing on "National Priorities for Solar and Space Physics Research and Applications for Space Weather Prediction." My name is Daniel Baker and I am a professor of astrophysical and planetary sciences at the University of Colorado. I am also the Director of the Laboratory for Atmospheric and Space Physics at CU-Boulder. The Laboratory is a research institute that has more than 60 teaching and research faculty in the several disciplines of space and Earth sciences. My institute, which we call LASP for short, receives some $60+ million per year to support experimental, theoretical, and data analysis programs in the Space and Earth Sciences. The majority of these resources come from NASA. But increasing support comes from NOAA, NSF, and other federal agencies. LASP presently supports some 130 engineers as well as dozens of highly skilled technicians and support personnel. We are very proud, as well, that LASP has nearly 70 graduate students and over 100 undergraduate students each year who are pursuing education and training goals in space science and engineering.

I myself am a space plasma physicist and I have served as a principal investigator on several scientific programs of NASA. I am now a lead investigator in the recently launched Radiation Belt Storm Probe (RBSP) mission that is part of NASA's Living With a Star program. I am also an investigator on NASA's Cluster, MESSENGER, and Magnetospheric Multi-Scale (MMS) missions. I recently served as Chair of the National Research Council's Committee on Solar and Space Physics and as a member of the NRC Space Studies Board. I am testifying today in my capacity as chair of the NRC Committee for a Decadal Strategy for Solar and Space Physics (Heliophysics), which recently published the report, *Solar and Space Physics: A Science for a Technological Society* (the "decadal survey"). The report is available online at: <http://www.nap.edu/catalog.php?record_id=13060>. Although my testimony follows the specific recommendations and supporting text in that report; the opinions I express should be attributed to me unless stated otherwise.

The charter for today's hearing includes 3 overarching questions:

1. What are the [decadal] survey committee's top recommendations for the coming decade? What is the current state of the solar and space physics programs at NASA and what are the prospects for the foreseeable future to follow the Decadal Survey's recommendations given that budgets will remain essentially flat?
2. What is the role of the Space Weather Prediction Center at NOAA? To what extent does NOAA work with NASA to develop and disseminate space weather models and forecasts? Where can coordination between agencies improve?

3. The recent solar and space physics decadal survey concluded that "a national, multifaceted program of both observations and modeling is needed to transition research into operations more effectively." What steps is each agency taking to ensure a solar and space physics research program is effectively maintained and improved?

In my testimony below, I address these questions sequentially; following the testimony, I have appended the Summary of decadal survey report, which provides a more comprehensive review of the decadal survey's origins, organization, objectives, and recommendations.

Background and Overview of the 2013-2022 Decadal Survey in Solar and Space Physics

From the interior of the Sun, to the upper atmosphere and near-space environment of Earth, and outwards to a region far beyond Pluto where the Sun's influence wanes, advances during the past decade in space physics and solar physics have yielded spectacular insights into the phenomena that affect our home in space. The decadal survey report, requested by NASA and the National Science Foundation, and carried out with their financial support and with the cooperation of other federal agencies, especially NOAA, presents a prioritized program of basic and applied research for 2013-2022 that will advance scientific understanding of the Sun, Sun- Earth connections and the origins of "space weather," and the Sun's interactions with other bodies in the solar system. The report includes recommendations directed for action by the study sponsors and by other federal agencies—especially NOAA, which is responsible for the day-to-day ("operational") forecast of space weather. Appended to this testimony is the executive summary of the decadal survey, which provides details on all of the survey report's recommendations.

The present decadal survey is the second NRC decadal survey in solar and space physics. Like all NRC decadal survey reports, this decadal survey was conducted with the assistance of a broad swath of the solar and space physics community; the final report represented the efforts of more than 85 solar and space physicists and space system engineers working over an 18-month period. In developing its recommendations, the survey committee also drew on over 300 "white papers" that were submitted by the community in response to a broadly-distributed survey request for concepts and new ideas to advance the discipline. The survey committee also sponsored numerous town-hall meetings and workshops prior to the formal start of its deliberations.

Per the study statement of work, the survey's top-level tasks were to:

1. Provide an overview of solar and space physics science and provide a broad survey of the current state of knowledge in the field;
2. Identify the most compelling science challenges;
3. Identify the highest priority scientific targets for the interval 2013-2022; and
4. Develop an integrated research strategy.

Survey Recommendations

The survey report's recommendations are shown in the report summary that is appended to this testimony. The recommended actions include completion of projects in NASA and the National Science Foundation's (NSF's) current program, creation of a new "mid-scale" projects line at NSF, augmentation of NASA and NSF "enabling" programs, and acceleration and expansion of NASA's Heliophysics Explorer Program. For later in the decade, the report recommends beginning new moderate-size NASA missions to address high-priority science targets, and a multiagency initiative to address pressing needs for improved forecasts of space weather and predictions of its impacts on society.

A key element of the survey is that its recommended program was fit to resources anticipated in a challenging fiscal environment. To ensure that the costs of the recommended NASA program were realistic, the NRC contracted with the Aerospace Corporation, who conducted an independent cost and technical evaluation (CATE) of selected reference mission concepts. In addition, the survey committee provided "decision rules" that can be employed to maintain the vitality of the program should the recommended program need to be adjusted because of unanticipated technical problems, cost overruns, or budget shortfalls. At the request of NASA, decision rules specific to the flagship mission Solar Probe Plus were also provided.

Four scientific goals inform the survey committee's recommendations:

1. Establish the origins of the sun's activity and predict the variations of the space environment;
2. Determine the dynamics and coupling of Earth's magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs;
3. Understand the interaction of the sun with the solar system and the interstellar medium; and
4. Discover and characterize fundamental processes that occur both within the heliosphere and throughout the universe.

Considering cost, schedule, and complexity, the decadal survey provides a number of research recommendations to reach these goals. It also considers challenges that could impede achievement of the recommended program, including budget issues, the necessity to coordinate activities across multiple agencies, and the limited availability of appropriately-sized and affordable space launch vehicles.

The report's first recommendation is to continue support for the key existing program elements that comprise the Heliophysics Systems Observatory and for successful implementation of programs in advanced stages of development. Second in priority is the establishment of a new, integrated multiagency initiative—"DRIVE"—that will more effectively exploit NASA and NSF scientific assets. Fully exploiting available resources is always a priority; in the highly constrained budgets anticipated in the foreseeable future, it is a necessity.

The DRIVE initiative has five components:

1. Diversify observing platforms with microsatellites and mid-scale ground-based assets;
2. Realize scientific potential by sufficiently funding operations and data analysis;
3. Integrate observing platforms and strengthen ties between agency disciplines;
4. Venture forward with science centers and instrument and technology development; and
5. Educate, empower, and inspire the next generation of space researchers.

As shown in Figure 1, below, the survey committee recommends a gradual implementation of the elements of DRIVE (because of budget constraints); in addition, elements of DRIVE are sequenced to take advantage of the implementation of new programs later in the decade survey interval. For example, Mission Operations and Data Analysis (MO&DA) augmentation begins in 2016, at a time when the Solar Dynamics Observatory (SDO) will have moved out of its prime mission phase, thus adding greatly to data covered by the general Guest Investigator (GI) program. The NASA portion of DRIVE is fully implemented by 2022, amounting to an augmentation to existing program lines that is equivalent to approximately $33 million in current (2013) dollars. Note: In developing the DRIVE run-outs, the survey committee assumes a 2.7% rate of inflation, which is what NASA currently assumes as the inflation factor to be used for its new starts.

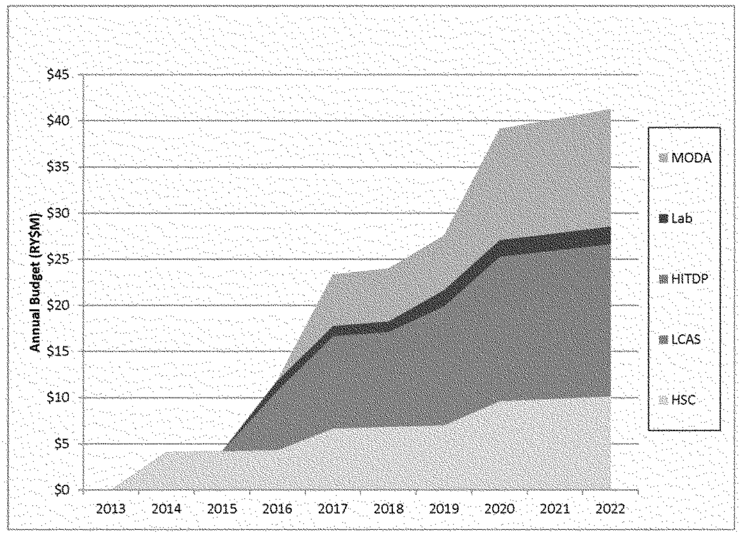


Figure 1: NASA DRIVE implementation: For the cost of a small mission, the DRIVE initiative recommends augmentations to NASA mission-enabling programs that have been carefully chosen to maximize the effectiveness of the program overall. Six of the DRIVE sub-recommendations have cost impact for NASA. Of these, *NASA Mission Guest Investigator* would require a cost allocation within STP and LWS missions of ~2% of total mission cost for a directed guest investigator program. The other five, *NASA LCAS Microsatellites (LCAS), MO&DA augmentation (MODA), Heliophysics Science Centers (HSCs), Heliophysics Instrument and Technology Development Program (HITDP), and Multi-agency Laboratory Experiments (Lab),* are shown in the figure.

Third, the report recommends that NASA accelerate and expand the Heliophysics Explorer program, which provides frequent flight opportunities to enable the definition, development and implementation of mission concepts. Informing this recommendation was the recognition that the solar and space physics community has done much of its best and most innovative research with Explorers, a program which had been reduced during the previous decade. A key objective for the next survey interval—2013-2022— is to restore the number of Medium and Explorer class missions such that, in combination with competitively selected Instrument Opportunities on hosted payloads (MOOs), a higher cadence can be achieved that is capable of maintaining the vitality of the science disciplines. Augmenting the current program by $70 million per year, in fiscal year 2012 dollars, will restore the option of mid-size Explorers and allow them to be offered in alternation with small explorers every 2 to 3 years. As part of the augmented Explorer program, it is also recommended that NASA support regular selections of Missions of Opportunity, which allow the research community to respond quickly and to leverage limited resources with interagency, international, and commercial flight partnerships. For relatively modest investments, such opportunities can potentially address high-priority science aims identified in this survey.

A highly constrained budget and the need to complete missions already in advanced stages of development postpones any new moderate- or large-class starts until midway in the survey interval of 2013-2022. Figure 2, below, shows a proposed implementation of the core NASA program, in which each of the assets required to achieve the goals of the solar and space physics program are implemented at what is considered a proper cadence and within a budget profile that should be attainable. The recommended program addresses in a cost effective manner many of the most important and interesting science objectives, but the anticipated budget significantly constrains what can be accomplished. Built on top of the existing research foundation, the core program recommended here ensures that a proper distribution of resources is achieved. In particular, it restores a balance between small, medium, and large missions.

As detailed in the survey report, 3 new moderate- and 1 large-class mission starts are recommendedlater in the decade to investigate space physics at the edge of heliosphere, where the sun's influence on interstellar space is no longer dominate; the effects of processes in Earth's lower atmosphere on conditions in space; fundamental questions related to the creation and transport of plasma in Earth's ionosphere and magnetosphere; and how the Earth responds globally to magnetic storms from the sun.

A key recommendation of the survey committee is that NASA's Solar-Terrestrial Probes program be restructured as a moderate-scale, competed, principal-investigator-led (PI-led) mission line that is cost-capped at approximately $520 million per mission in fiscal year 2012 dollars including full life-cycle costs. NASA's Planetary Science Division has demonstrated success in implementing mid-size missions as competed, cost-capped, PI-led investigations via the Discovery and New Frontiers programs. These are managed in a manner similar to Explorers and have a superior cost-performance history relative to that of larger flagship missions. The committee concluded that STP missions should be managed likewise, with the PI empowered to make scientific and mission design trade-offs necessary to remain within the cost cap. With larger-class LWS missions, which the committee recommends to continue to be Center-led, and smaller-class Explorers and Missions of Opportunity, this new approach will lead to a more balanced and effective overall NASA HPD mission portfolio that is implemented at a higher cadence and provides the vitality needed to accomplish the breadth of the survey's science goals. The eventual recommended minimum cadence of STP missions is one every 4 years.

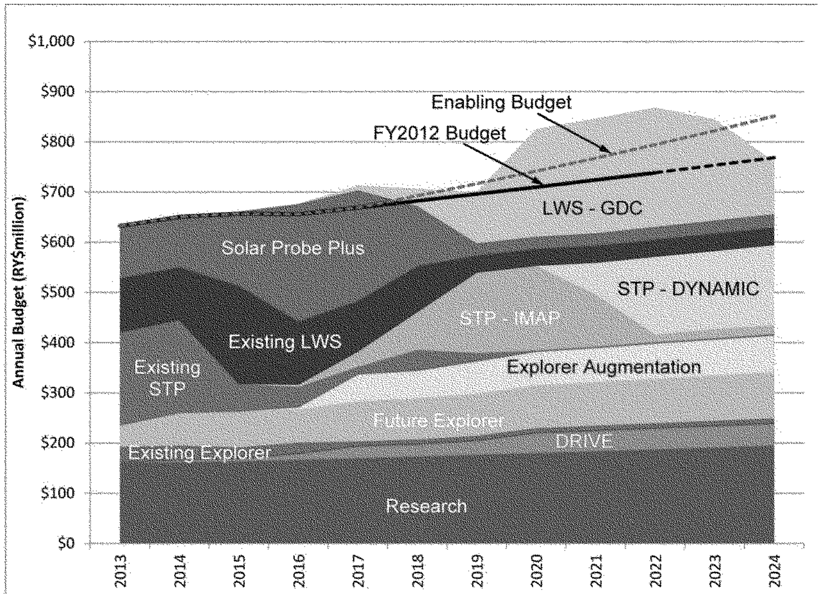


Figure 2: Heliophysics budget and program plan by year and category from 2013 to 2024. The solid black line indicates the funding level from 2013 to 2022 provided to the committee by NASA as the baseline for budget planning, and the dashed black line extrapolates the budget forward to 2024. After 2017 the amount increases with a nominal 2 percent inflationary factor. Through 2016 the program content is tightly constrained by budgetary limits and fully committed for executing existing program elements. The red dashed "Enabling Budget" line includes a modest increase from the baseline budget starting in 2017, allowing implementation of the survey-recommended program at a more efficient cadence that better meets scientific and societal needs and improves optimization of the mix of small and large missions. From 2017 to 2024 the Enabling Budget grows at 1.5 percent above inflation. (Note that the 2024 Enabling Budget is equivalent to growth at a rate just 0.50 percent above inflation from 2009.) GDC, the next large mission of the LWS program after SPP, rises above the baseline curve in order to achieve a more efficient spending profile, as well as to achieve deployment in time for the next solar maximum in 2024. Note: LWS refers to missions in the Living With a Star line and STP refers to missions in the Solar-Terrestrial Probes line.

Enabling Effective Space Weather and Climatology Capabilities

NASA research satellites, such as ACE, SOHO (with ESA), STEREO, and SDO, designed for scientific studies, provide critical measurements essential for specifying and forecasting the space environment system, including the outward propagation of eruptive solar events and solar wind conditions upstream from Earth. While these observational capabilities have become essential for space environment operations, climatological monitoring, and research, NASA currently has neither the mandate nor the budget to sustain these measurements into the future.

A growing literature has documented the need to provide a long-term strategy for monitoring in space, and elucidated the large number of space weather effects, the forecasting of which depend critically on the availability of suitable data streams.[1] An example is the provision of measurements of particles and fields at the L1 Lagrange point (or, using technologies such as solar sails, closer to the Sun on the Sun-Earth line), which is critical for short term forecasting of harmful space weather effects such as radiation, GPS accuracy reduction, and potentially deleterious geomagnetically induced currents on the power grid. The decadal survey steering committee found that the existing ad hoc approach towards the provision of these capabilities was inadequate.

A new plan is also needed that synthesizes and capitalizes on the strengths of the agencies participating in the NSWP as well as on opportunities in the commercial sector, such as the Active Magnetosphere and Planetary Electrodynamics Response Experiment (AMPERE) that uses the Iridium constellation of communications satellites to measure the electric currents that link Earth's atmosphere and space. The committee sees a need for a clearinghouse for coordinating the acquisition, processing, and archiving of underutilized real-time and near real-time ground- and space-based data needed for space weather applications. For example, highly valued energetic particle measurements made by GPS and LANL GEO satellites for specification of the radiation belts are not now routinely provided. Likewise, model development has been supported by individual agencies rather than being coordinated across relevant stakeholders.

In the survey report, the committee articulates a vision for an enhanced national commitment by partnering agencies for continuous measurements of critical space environment parameters, analogous to the monitoring of the terrestrial environment NASA is conducting in collaboration with a number of other agencies, for example, NOAA and the U.S. Geological Survey (USGS). The committee anticipates the criticality of such a program growing in priority relative to other societal demands and envisions that NASA utilize its unique space-based capabilities as the basis for a new program that could provide sustained monitoring of key space environment observables to meet this pressing national need. In addition to ensuring the continuity of critical measurements, robust space environment models capable of operational deployment are also necessary for the prediction and specification of conditions where observations are lacking.

The committee anticipates that it will take decades to achieve a space environment weather and climatology infrastructure equivalent to current capabilities in the modeling and forecasting of terrestrial weather and climate; thus, it is necessary to start immediately. The committee's vision for achieving critical continuity of key space environment parameters, their utilization in advanced models and application to operations is a major endeavour that will require unprecedented cooperation among agencies in areas where they have specific expertise and unique capabilities.

Space Weather-Related Recommendations

The following recommendations were made by the survey committee to help fulfill its vision of an effective program in space weather that meets national needs—one that advances the fundamental science that underpins understanding of space weather phenomena and its effects on society and the evident need for effective vehicles to translate newly gained knowledge towards societal benefit:

Recharter the National Space Weather Program: The survey committee recommends that, to coordinate the development of this plan, the National Space Weather Program should be rechartered under the auspices of the National Science and Technology Council and should include the active participation of the Office of Science and Technology Policy and the Office of Management and Budget.

[1] See, for example, National Research Council, *Severe Space Weather Events—Understanding Societal and Economic Impacts: A Workshop Report*, The National Academies Press, Washington, D.C., 2008, and D.N. Baker and L.J. Lanzerotti, A continuous L1 presence required for space weather, *Space Weather* 6:S11001, doi:10.1029/2008SW000445, 2008.

The plan should build on current agency efforts, leverage the new capabilities and knowledge that will arise from implementation of the programs recommended in this report, and develop additional capabilities, on the ground and in space, that are specifically tailored to space weather monitoring and prediction.

Work in a multi-agency partnership to achieve continuity of solar and solar wind observations: The survey committee recommends that NASA, NOAA, and the Department of Defense work in partnership to plan for continuity of solar and solar wind observations beyond the lifetimes of ACE, SOHO, STEREO, and SDO. In particular:

- Solar wind measurements from L1 should be continued, because they are essential for space weather operations and research. The DSCOVR and IMAP STP missions are recommended for the near term, but plans should be made to ensure that measurements from L1 continue uninterrupted into the future.
- Space-based coronagraph and solar magnetic field measurements should likewise be continued.

Further, the survey committee concluded that a national, multifaceted program of both observations and modeling is needed to transition research into operations more effectively by fully leveraging expertise from different agencies, universities, and industry and by avoiding duplication of effort. This effort should include determining the operationally optimal set of observations and modeling tools and how best to effect that transition. With these objectives in mind, the committee recommends that:

- **The space weather community should evaluate new observations, platforms, and locations that have the potential to provide improved space weather services. In addition, the utility of employing newly emerging information dissemination system for space weather alerts should be assessed.**
- **NOAA should establish a space weather research program to effectively transition research to operations.**
- **Distinct funding lines for basic space physics research and for space weather specification and forecasting need to be developed and maintained.**

Implementation of a program to advance space weather and climatology will require funding well above what the survey committee assumes will be available to support its research-related recommendations to NASA. The committee emphasizes that implementation of an initiative in space weather and climatology should proceed only if it does not impinge on the development and timely execution of the recommended research program.

Thank you again for the opportunity to bring to your attention the results of the 2nd National Research Council decadal survey in solar and space physics. At your request, I've focused my remarks on several questions that have particular relevance to NASA and its Science Mission Directorate; however, as the discussion of space weather indicates, multiple federal agencies have vital interests how we organize the nation's efforts in solar and space physics research and applications. In summary, our report:

- Fits the current fiscal boundary;
- Focuses on research and its societal impact;
- Empowers the community to innovate;
- Takes advantage of the unique constellation of missions and data available today and studies the coupled domains of heliophysics *as a system;*

- Builds the community's strength and facilitates development of cost-effective PI-class missions; and
- Recommends exciting missions of historical significance that hold tremendous promise for new discoveries.

Solar and Space Physics: A Science for a Technological Society

Summary

From the interior of the Sun, to the upper atmosphere and near-space environment of Earth, and outward to a region far beyond Pluto where the Sun's influence wanes, advances during the past decade in space physics and solar physics—the disciplines NASA refers to as heliophysics—have yielded spectacular insights into the phenomena that affect our home in space. This report, from the National Research Council's (NRC's) Committee for a Decadal Strategy in Solar and Space Physics, is the second NRC decadal survey in heliophysics. Building on the research accomplishments realized over the past decade, the report presents a program of basic and applied research for the period 2013-2022 that will improve scientific understanding of the mechanisms that drive the Sun's activity and the fundamental physical processes underlying near-Earth plasma dynamics, determine the physical interactions of Earth's atmospheric layers in the context of the connected Sun-Earth system, and enhance greatly the capability to provide realistic and specific forecasts of Earth's space environment that will better serve the needs of society. Although the recommended program is directed primarily to NASA (Science Mission Directorate–Heliophysics Division) and the National Science Foundation (NSF) (Directorate for Geosciences–Atmospheric and Geospace Sciences) for action, the report also recommends actions by other federal agencies, especially the National Oceanic and Atmospheric Administration (NOAA) those parts of NOAA charged with the day-to-day (operational) forecast of space weather. In addition to the recommendations included in this summary, related recommendations are presented in the main text of the report.

RECENT PROGRESS: SIGNIFICANT ADVANCES FROM THE PAST DECADE

As summarized in Chapter 3 and discussed in greater detail in Chapters 8-10, the disciplines of solar and space physics have made remarkable advances over the last decade—many of which have come from the implementation of the program recommended in the 2003 solar and space physics decadal survey.[2] Listed below are some of the highlights from an exciting decade of discovery:

- New insights, gained from novel observations and advances in theory, modeling, and computation, into the variability of the mechanisms that generate the Sun's magnetic field, and into the structure of that field;
- A new understanding of the unexpectedly deep minimum in solar activity;
- Significant progress in understanding the origin and evolution of the solar wind;
- Striking advances in understanding both explosive solar flares and the coronal mass ejections that drive space weather;
- Groundbreaking discoveries about the surprising nature of the boundary between the heliosphere—that is, the immense magnetic bubble containing our solar system—and the surrounding interstellar medium;
- New imaging methods that permit researchers to directly observe space weather-driven changes in the particles and magnetic fields surrounding Earth;

[2] National Research Council, *The Sun to the Earth—and Beyond: A Decadal Research Strategy in Solar and Space Physics*, The National Academies Press, Washington, D.C., 2003; and National Research Council, *The Sun to the Earth—and Beyond: Panel Reports*, The National Academies Press, Washington, D.C., 2003.

- Significantly deeper knowledge of the numerous processes involved in the acceleration and loss of particles in Earth's radiation belts;
- Major advances in understanding the structure, dynamics, and linkages in other planetary magnetospheres, especially those of Mercury, Jupiter, and Saturn;
- New understanding of how oxygen from Earth's own atmosphere contributes to space storms;
- The surprising discovery that conditions in near-Earth space are linked strongly to the terrestrial weather and climate below;
- The emergence of a long-term decline in the density of Earth's upper atmosphere, indicative of planetary change; and
- New understanding of the temporal and spatial scales involved in magnetospheric-atmospheric coupling in Earth's aurora.

It is noteworthy that some of the most surprising discoveries of the past decade have come from comparatively small missions that were tightly cost-constrained, competitively selected, and principal investigator (PI)-led—recommendations in the present decadal survey reflect this insight.

Enabled by advances in scientific understanding as well as fruitful interagency partnerships, the capabilities of models that predict space weather impacts on Earth have also made rapid gains over the past decade. Reflecting these advances and a society increasingly vulnerable to the adverse effects of space weather, the number of users of space weather services has also grown rapidly. Indeed, a growing community has come to depend on constant and immediate access to space weather information (Chapter 7).

SCIENCE GOALS FOR THE NEXT DECADE

The significant achievements of the past decade set the stage for *transformative* advances in solar and space physics for the coming decade. Reports from the survey's three interdisciplinary study panels (Chapters 8-10) enumerate the key scientific opportunities and challenges for the coming decade; collectively, they inform the survey's four overarching science goals, each of which is considered of equal priority:

> ***Goal 1. Determine the origins of the Sun's activity and predict the variations in the space environment.***
>
> ***Goal 2. Determine the dynamics and coupling of Earth's magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs.***
>
> ***Goal 3. Determine the interaction of the Sun with the solar system and the interstellar medium.***
>
> ***Goal 4. Discover and characterize fundamental processes that occur both within the heliosphere and throughout the universe.***

GUIDING PRINCIPLES AND PROGRAMMATIC CHALLENGES

To achieve these science goals, the survey committee recommends adherence to the following principles (Chapter 1):

- To make transformational scientific progress, the Sun, Earth, and heliosphere must be studied as a coupled system;

- To understand the coupled system requires that each subdiscipline be able to make measurable advances in achieving its key science goals; and
- Success across the entire field requires that the various elements of solar and space physics research programs—the enabling foundation comprising theory, modeling, data analysis, innovation, and education, as well as ground-based facilities and small-, medium-, and large-class space missions—be deployed with careful attention both to the mix of assets and to the schedule (cadence) that optimizes their utility over time.

The committee's recommendations reflect these principles while also taking into account issues of cost, schedule, and complexity. The committee also recognizes a number of challenges that could impede achievement of the recommended program: the assumed budget may not be realized or missions could experience cost growth; the necessity to coordinate activities across multiple agencies; and the limited availability of appropriately sized and affordable space launch vehicles, particularly medium-class launch vehicles.

RECOMMENDATIONS—RESEARCH AND APPLICATIONS

The survey committee's recommendations are listed in Tables S.1 and S.2; a more complete discussion of the "research" recommendations—the primary focus of this survey—is found in Chapter 4 along with a discussion of the "applications" recommendations, while Chapter 7 presents the committee's vision, premised on the availability of additional funds, of an expanded program in space weather and space climatology. The committee's recommendations are prioritized and integrated across agencies to form an effective set of programs consistent with fiscal and other constraints. An explicit cost appraisal for each NASA research recommendation is incorporated into the budget for the overall program (Chapter 6); however, for NSF programs, only a general discussion of expected costs is provided (Chapter 5).

Research Recommendations

Baseline Priority for NASA and NSF: Complete the Current Program

The survey committee's recommended program for NSF and NASA assumes continued support in the near term for the key existing program elements that constitute the Heliophysics Systems Observatory (HSO) and successful implementation of programs in advanced stages of development.

NASA's existing heliophysics flight missions and NSF's ground-based facilities form a network of observing platforms that operate simultaneously to investigate the solar system. This array can be thought of as a single observatory—the Heliophysics System Observatory (HSO) (see Figure 1.2). The evolving HSO lies at the heart of the field of solar and space physics and provides a rich source of observations that can be used to address increasingly interdisciplinary and long-term scientific questions. Missions now under development will expand the HSO and drive scientific discovery. For NASA, these include the following:

- The Radiation Belt Storm Probes (RBSP, Living With a Star (LWS) program, 2012 launch) and related Balloon Array for RBSP Relativistic Electron Losses (BARREL; first launch 2013) will determine the mechanisms that control the energy, intensity, spatial distribution, and time variability of Earth's radiation belts.
- The Interface Region Imaging Spectrograph (IRIS; Explorer program, 2013 launch) will deliver pioneering observations of chromospheric dynamics just above the solar surface to help determine their role in the origin of the heat and mass fluxes into the corona and wind.

- The Magnetospheric Multiscale mission (MMS; Solar-Terrestrial Probe (STP) program, 2014 launch) will address the physics of magnetic reconnection at the previously inaccessible tiny scale where reconnection is triggered.

Compelling missions that are not yet in advanced stages of development but are part of a baseline program whose continuation NASA asked the survey committee to assume include the following:[3]

- Solar Orbiter (European Space Agency-NASA partnership, 2017 launch) will investigate links between the solar surface, corona, and inner heliosphere from as close as 62 solar radii.
- Solar Probe Plus (SPP, LWS program, 2018 launch) will make mankind's first visit to the solar corona to discover how the corona is heated, how the solar wind is accelerated, and how the Sun accelerates particles to high energy.

With these new investments, the powerful fleet of space missions that explore our local cosmos can be significantly strengthened. However, implementation of the baseline program will consume nearly all of the resources anticipated to be available for new starts within NASA's Heliophysics Division through the midpoint of the overall survey period, 2013-2022.

For NSF, the previous decade witnessed the initial deployment in Alaska of the Advanced Modular Incoherent Scatter Radar (AMISR), a mobile facility used to study the upper atmosphere and to observe space weather events, and the initial development of the Advanced Technology Solar Telescope (ATST), a 4-meter-aperture optical solar telescope—by far the largest in the world—that will provide the most highly resolved measurements ever obtained of the Sun's plasma and magnetic field. These new NSF facilities join a broad range of existing ground-based assets that provide an essential global synoptic perspective and complement space-based measurements of the solar and space physics system. With adequate science and operations support, they will enable frontier research even as they add to the long-term record necessary for analyzing space climate over solar cycles.

R1.0 Implement the DRIVE Initiative

The survey committee recommends implementation of a new, integrated, multiagency initiative (DRIVE—Diversify, Realize, Integrate, Venture, Educate) that will develop more fully and employ more effectively the many experimental and theoretical assets at NASA, NSF, and other agencies.

The DRIVE initiative encompasses specific, cost-effective, augmentations to NASA and NSF heliophysics programs. Its implementation will bring existing "enabling" programs to full fruition and will provide new opportunities to realize scientific discoveries from existing data, build more comprehensive models, make theoretical breakthroughs, and innovate. With this in mind, the committee has as its first priority for both NASA and NSF (after completion of the current program) the implementation of an integrated, multiagency initiative comprising the following components:

- Diversify observing platforms with microsatellites and mid-scale ground-based assets
- Realize scientific potential by sufficiently funding operations and data analysis
- Integrate observing platforms and strengthen ties between agency disciplines
- Venture forward with science centers and instrument and technology development
- Educate, empower, and inspire the next generation of space researchers

[3] In accordance with its statement of task, the survey committee did not reprioritize any NASA mission that was in formulation or advanced development. In addition, the study charge specified that Solar Orbiter and Solar Probe Plus would not be included in any prioritization of future mission opportunities.

The five DRIVE components are defined in Chapter 4, with specific and actionable recommendations for each element. Implementation of the NASA portion of the DRIVE initiative would require an augmentation to existing program lines equivalent to approximately $33 million in current (2013) dollars (see Chapter 6).[4] The cost and implementation of the NSF portion of DRIVE are described in Chapter 5. Although the recommendations for NSF within the DRIVE initiative are not prioritized, the survey committee calls attention to two in particular:

The National Science Foundation should:

- **Provide funding sufficient for essential synoptic observations and for efficient and scientifically productive operation of the Advanced Technology Solar Telescope (ATST), which provides a revolutionary new window on the solar magnetic atmosphere.**
- **Create a new competitively selected mid-scale project funding line in order to enable mid-scale projects and instrumentation for large projects.** There are a number of compelling candidates for a mid-scale facilities line, including the Frequency Agile Solar Radiotelescope (FASR), the Coronal Solar Magnetism Observatory (COSMO), and several other projects exemplifying the kind of creative approaches necessary to fill gaps in observational capabilities and to move the survey's integrated science plan forward.

R2.0 Accelerate and Expand the Heliophysics Explorer Program

The survey committee recommends that NASA accelerate and expand the Heliophysics Explorer program. Augmenting the current program by $70 million per year, in fiscal year 2012 dollars, will restore the option of Mid-size Explorer (MIDEX) missions and allow them to be offered alternately with Small Explorer (SMEX) missions every 2 to 3 years. As part of the augmented Explorer program, NASA should support regular selections of Missions of Opportunity.

The Explorer program's strength lies in its ability to respond rapidly to new concepts and developments in science, as well as in the program's synergistic relationship with larger-class strategic missions.[5] The Explorer mission line has proven to be an outstanding success, delivering—cost-effectively—science results of great consequence. The committee recommends increased support of the Explorer program to enable significant scientific advances in solar and space physics. As discussed in Chapter 4, the committee believes that the proper cadence for Heliophysics Explorers is one mission every 2 to 3 years. The committee's recommended augmentation of the Explorer program would facilitate this cadence and would also allow selection of both small- and medium-class Explorers. Historically, MIDEX missions offered an opportunity to resolve many of the highest-level science questions, but they have not been feasible with the current Explorer budget.

Regular selections of Missions of Opportunity will also allow the research community to respond quickly and to leverage limited resources with interagency, international, and commercial flight partnerships. For relatively modest investments, such opportunities can potentially address high-priority science aims identified in this survey.

R3.0 Restructure Solar-Terrestrial Probes as a Moderate-Scale, PI-Led Line

---

[4] The survey committee assumes inflation at 2.7 percent in program costs, the same as the percentage used by NASA for new starts.

[5] National Research Council, *Solar and Space Physics and Its Role in Space Exploration,* The National Academies Press, Washington, D.C., 2003, p. 36.

The survey committee recommends that NASA's Solar-Terrestrial Probes program be restructured as a moderate-scale, competed, principal-investigator-led (PI-led) mission line that is cost-capped at $520 million per mission in fiscal year 2012 dollars including full life-cycle costs.

NASA's Planetary Science Division has demonstrated success in implementing mid-size missions as competed, cost-capped, PI-led investigations via the Discovery and New Frontiers programs. These are managed in a manner similar to Explorers and have a superior cost-performance history relative to that of larger flagship missions. The committee concluded that STP missions should be managed likewise, with the PI empowered to make scientific and mission design trade-offs necessary to remain within the cost cap (Chapter 4). With larger-class LWS missions and smaller-class Explorers and Missions of Opportunity, this new approach will lead to a more balanced and effective overall NASA HPD mission portfolio that is implemented at a higher cadence and provides the vitality needed to accomplish the breadth of the survey's science goals. The eventual recommended minimum cadence of STP missions is one every 4 years.

Although the new STP program would involve moderate missions being chosen competitively, the survey committee recommends that their science targets be ordered as follows so as to systematically advance understanding of the full coupled solar-terrestrial system:

R3.1 The first new STP science target is to understand the outer heliosphere and its interaction with the interstellar medium, as illustrated by the reference mission[6] Interstellar Mapping and Acceleration Probe (IMAP; Chapter 4). Implementing IMAP as the first of the STP investigations will ensure coordination with NASA Voyager missions. The mission implementation also requires measurements of the critical solar wind inputs to the terrestrial system.

R3.2 The second STP science target is to provide a comprehensive understanding of the variability in space weather driven by lower-atmosphere weather on Earth. This target is illustrated by the reference mission Dynamical Neutral Atmosphere-Ionosphere Coupling (DYNAMIC; Chapter 4).

R3.3 The third STP science target is to determine how the magnetosphere-ionosphere-thermosphere system is coupled and how it responds to solar and magnetospheric forcing. This target is illustrated by the reference mission Magnetosphere Energetics, Dynamics, and Ionospheric Coupling Investigation (MEDICI; Chapter 4).

The rationale for all the selections and for their ordering is detailed in Chapter 4.

Living With a Star

Certain landmark scientific problems are of such scope and complexity that they can be addressed only with major missions. In the survey committee's plan, major heliophysics missions would be implemented within NASA's LWS program; the survey committee recommends that they continue to be

[6] In this report, the committee uses the terms "reference mission" and "science target" interchangeably, given that the mission concepts were developed specifically to assess the cost of addressing particular high-priority science investigations. The concepts presented in this report underwent an independent cost and technical analysis by the Aerospace Corporation, and they have been given names for convenience; however, the actual recommendation from the committee is to address the science priorities enumerated in the reference mission concept.

managed and executed by NASA centers. Other integral thematic elements besides the flight program are essential to the LWS science and technology program: the unique LWS research, technology, strategic capabilities, and education programs remain of great value.

R4.0 Implement a large Living With a Star mission to study the ionosphere-thermosphere-mesosphere system in an integrated fashion.

The survey committee recommends that, following the launch of RBSP and SPP, the next LWS science target focus on how Earth's atmosphere absorbs solar wind energy. The recommended reference mission is Geospace Dynamics Constellation (GDC).

As detailed in Chapter 4, the GDC reference mission would provide crucial scientific measurements of the extreme variability of conditions in near-Earth space. Within anticipated budgets, the completion of the baseline LWS program, which includes the launch of two major missions—RBSP in 2012 and SPP in 2018—does not allow for the launch of a subsequent major mission in heliophysics until 2024, 6 years after SPP. This establishes what the survey committee regards as the absolute minimum needed cadence for major missions.

Applications Recommendations: Enabling Effective Space Weather and Climatology Capabilities

Multiple agencies of the federal government have vital interests related to space weather, and efforts to coordinate these agencies' activities are seen in the National Space Weather Program (NSWP).[7] Nonetheless, the survey committee concluded that additional approaches are needed to develop the capabilities outlined in the 2010 National Space Policy document and envisioned in the 2010 NSWP plan. Chapter 7 presents the committee's vision for a renewed national commitment to a comprehensive program in space weather and climatology (SWaC). Enabling an effective SWaC capability will require action across multiple agencies and an integrated program that builds on the strengths of individual agencies.

A1.0 Recharter the National Space Weather Program

The survey committee recommends that, to coordinate the development of this plan, the National Space Weather Program should be rechartered under the auspices of the National Science and Technology Council and should include the active participation of the Office of Science and Technology Policy and the Office of Management and Budget. The plan should build on current agency efforts, leverage the new capabilities and knowledge that will arise from implementation of the programs recommended in this report, and develop additional capabilities, on the ground and in space, that are specifically tailored to space weather monitoring and prediction.

A2.0 Work in a multi-agency partnership to achieve continuity of solar and solar wind observations.

The survey committee recommends that NASA, NOAA, and the Department of Defense work in partnership to plan for continuity of solar and solar wind observations beyond the lifetimes of ACE, SOHO, STEREO, and SDO. In particular:

---

[7] Committee for Space Weather, Office of the Federal Coordinator for Meteorological Services and Supporting Research, *National Space Weather Program Strategic Plan,* FCM-P30-2010, August 17, 2010, available at http://www.ofcm.gov/nswp-sp/fcm-p30.htm.

A2.1 Solar wind measurements from L1 should be continued, because they are essential for space weather operations and research. The DSCOVR and IMAP STP missions are recommended for the near term, but plans should be made to ensure that measurements from L1 continue uninterrupted into the future.

A2.2 Space-based coronagraph and solar magnetic field measurements should likewise be continued.

Further, the survey committee concluded that a national, multifaceted program of both observations and modeling is needed to transition research into operations more effectively by fully leveraging expertise from different agencies, universities, and industry and by avoiding duplication of effort. This effort should include determining the operationally optimal set of observations and modeling tools and how best to effect that transition. With these objectives in mind:

A2.3 The space weather community should evaluate new observations, platforms, and locations that have the potential to provide improved space weather services. In addition, the utility of employing newly emerging information dissemination system for space weather alerts should be assessed.

A2.4 NOAA should establish a space weather research program to effectively transition research to operations.

A2.5 Distinct funding lines for basic space physics research and for space weather specification and forecasting need to be developed and maintained.

Implementation of a program to advance space weather and climatology will require funding well above what the survey committee assumes will be available to support its research-related recommendations to NASA (see Table S.1). The committee emphasizes that implementation of an initiative in space weather and climatology should proceed only if it does not impinge on the development and timely execution of the recommended research program.

RECOMMENDED PROGRAM, DECISION RULES, AND AUGMENTATION PRIORITIES FOR NASA

Recommended Program

The committee's recommended program for NASA Heliophysics Division is shown in Figure S.1. As detailed in Chapter 6, the plan restores the medium-class Explorers and, together with small-class Explorer missions and Missions of Opportunity, achieves the recommended minimum mission cadence. The plan also begins the DRIVE initiative as early in the decade as budgets allow, with full implementation achieved by mid-decade. However, funding constraints affect the restoration and recommended rebalance of heliophysics program elements such that full realization of the survey committee's strategy is not possible until after 2017 (Figure S.1).

Decision Rules to Ensure Balanced Progress is Maintained

The recommended program for NASA cost-effectively addresses key science objectives. However, the survey committee recognizes that the already tightly constrained program could face further budgetary challenges. For example, with launch planned in 2018, the Solar Probe Plus project has not yet entered the implementation phase when expenditures are highest.[8] Significant cost growth in this very important, but technically challenging, mission beyond the current cap has the potential to disrupt the overall NASA heliophysics program.

To guide the allocation of reduced resources, the committee recommends the following decision rules intended to provide flexibility and efficiency if funding is less than anticipated, or should some other disruptive event occur. These rules, discussed in greater depth in Chapter 6, maintain progress toward the top-priority, system-wide science challenges identified in this survey. The decision rules should be applied in the order shown to minimize disruption of higher-priority program elements:

> *Decision Rule 1.* Missions in the STP and LWS lines should be reduced in scope or delayed to accomplish higher priorities (Chapter 6 gives explicit triggers for review of Solar Probe Plus).
>
> *Decision Rule 2.* If further reductions are needed, the recommended increase in the cadence of Explorer missions should be scaled back, with the current cadence maintained as the minimum.
>
> *Decision Rule 3.* If still further reductions are needed, the DRIVE augmentation profile should be delayed, with the current level of support for elements in the NASA research line maintained as the minimum.

Augmentations to Increase Program Value

The committee notes that the resources assumed in crafting this decadal survey's recommended programs are barely sufficient to make adequate progress in solar and space physics; with reduced resources, progress will be inadequate. It is also evident that with increased resources, the pace at which the nation pursues its program could be accelerated with a concomitant increase in the achievement of scientific discovery and societal value. The committee recommends the following augmentation priorities to aid in implementing a program under a more favorable budgetary environment:

> *Augmentation Priority 1.* Given additional budget authority early in the decade, the implementation of the DRIVE initiative should be accelerated.
>
> *Augmentation Priority 2.* With sufficient funds throughout the decade, the Explorer line should be further augmented to increase the cadence and funding available for missions, including Missions of Opportunity.
>
> *Augmentation Priority 3.* Given further budget augmentation, the schedule of STP missions should advance to allow the third STP science target (MEDICI) to begin in this decade.
>
> *Augmentation Priority 4.* The next LWS mission (GDC) should be implemented with an accelerated, more cost-effective funding profile.

EXPECTED BENEFITS OF THE RECOMMENDED PROGRAM

Implementation of the survey committee's recommended programs will ensure that the United States maintains its leadership in solar and space physics and, the committee believes, lead to significant—even transformative—advances in scientific understanding and observational capabilities (Table S.3). In turn, these advances will support critical national needs for information that can be used to

[8] On January 31, 2012, Solar Probe Plus passed its agency-level confirmation review and entered what NASA refers to as mission definition or Phase B of its project life cycle.

anticipate, recognize, and mitigate space weather effects that threaten to human life and the technological systems society depends on.

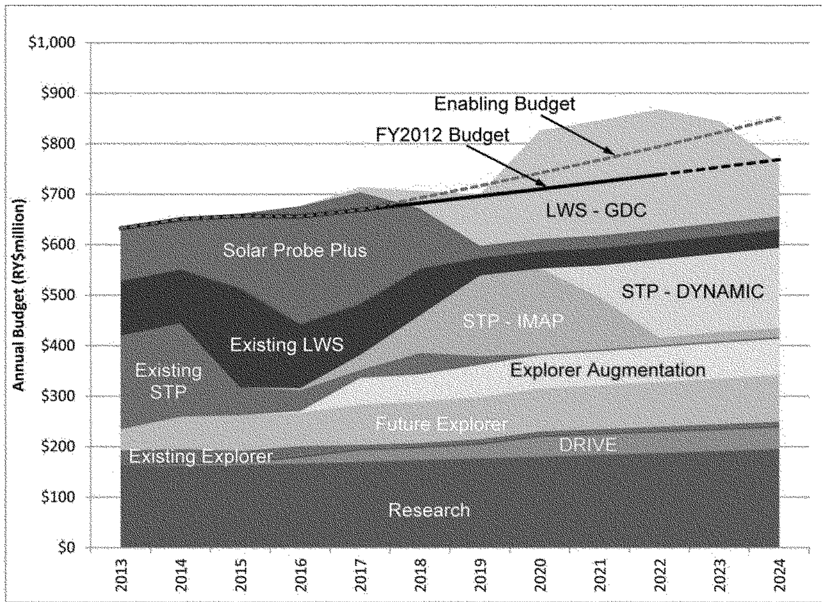


FIGURE S.1 Heliophysics budget and program plan by year and category from 2013 to 2024. The solid black line indicates the funding level from 2013 to 2022 provided to the committee by NASA as the baseline for budget planning, and the dashed black line extrapolates the budget forward to 2024. After 2017 the amount increases with a nominal 2 percent inflationary factor. Through 2016 the program content is tightly constrained by budgetary limits and fully committed for executing existing program elements. The red dashed "Enabling Budget" line includes a modest increase from the baseline budget starting in 2017, allowing implementation of the survey-recommended program at a more efficient cadence that better meets scientific and societal needs and improves optimization of the mix of small and large missions. From 2017 to 2024 the Enabling Budget grows at 1.5 percent above inflation. (Note that the 2024 Enabling Budget is equivalent to growth at a rate just 0.50 percent above inflation from 2009.) GDC, the next large mission of the LWS program after SPP, rises above the baseline curve in order to achieve a more efficient spending profile, as well as to achieve deployment in time for the next solar maximum in 2024. NOTE: LWS refers to missions in the Living With a Star line and STP refers to missions in the Solar-Terrestrial Probes line.

TABLE S.1 Summary of Top-Level Decadal Survey Research Recommendations

0.0	Complete the current program	X	X	
1.0	Implement the DRIVE initiative	X	X	X
	Small satellites; mid-scale NSF projects; vigorous ATST and synoptic program support; science centers and grant programs; instrument development			
2.0	Accelerate and expand the Heliophysics Explorer program	X		
	Enable MIDEX line and Missions of Opportunity			
3.0	Restructure STP as a moderate-scale, PI-led line	X		
3.1	Implement an IMAP-Like Mission	X		
3.2	Implement a DYNAMIC-Like Mission	X		
3.3	Implement a MEDICI-Like Mission	X		
4.0	Implement a large LWS GDC-like mission	X		

TABLE S.2 Summary of Top Level Decadal Survey Applications Recommendations

1.0	Recharter the National Space Weather Program	X	X	X
2.0	Work in a multi-agency partnership for solar and solar wind observations	X	X	X
2.1	Continuous solar wind observations from L1 (DSCOVR, IMAP)	X		X
2.2	Continue space-based coronagraph and solar magnetic field measurements	X		X
2.3	Evaluate new observations, platforms, and locations	X	X	X
2.4	Establish a SWx research program at NOAA to effectively transition from research to operations			X
2.5	Develop and maintain distinct programs for space physics	X	X	X

research and space weather specification and forecasting

TABLE S.3 Fulfilling the Science Goals of the Decadal Survey

Advances in Scientific Understanding and Observational Capabilities		Goals
Advances due to Implementation of the existing program	Twin Radiation Belt Storm Probes will observe Earth's radiation belts from separate locations, finally resolving the importance of temporal and spatial variability in the generation and loss of trapped radiation that threatens spacecraft.	2, 4
	The Magnetospheric Multiscale mission will provide the first high-resolution, three-dimensional measurements of magnetic reconnection in the magnetosphere, by sampling small regions where magnetic field line topologies reform.	2, 4
	Solar Probe Plus will be the first spacecraft to enter the outer atmosphere of the Sun, repeatedly sampling solar coronal particles and fields to understand coronal heating, solar wind acceleration, and formation and transport of energetic solar particles.	1, 4
	Solar Orbiter will provide the first high-latitude images and spectral observations of the Sun's magnetic field, flows, and seismic waves, relating changes seen in the corona to local measurements of the resulting solar wind.	1, 4
	The 4-meter Advanced Technology Solar Telescope will resolve structures as small as 20 km, measuring the dynamics of the magnetic field at the solar surface down to the fundamental density length scale and in the low corona.	1, 4
	The Heliophysics Systems Observatory will gather a broad range of ground- and space-based observations and advance increasingly interdisciplinary and long-term solar and space physics science objectives.	All
New starts on programs and missions to be implemented within the next decade	The DRIVE initiative will greatly strengthen our ability to pursue innovative observational, theoretical, numerical, modeling, and technical advances.	All
	Solar and space physicists will accomplish high-payoff, timely science goals with a revitalized Explorer program, including leveraged Missions of Opportunity.	All
	The Interstellar Mapping and Acceleration Probe, in conjunction with the twin Voyager spacecraft, will resolve the interaction between the heliosphere, our home in space, and the interstellar medium.	2, 3, 4
	A new funding line for mid-size projects at the National Science Foundation will facilitate long-recommended ground-based projects, such as COSMO and FASR, by closing the funding gap between large and small programs.	All
New starts on missions to be launched early in the next decade	The Dynamical Neutral Atmosphere-Ionosphere Coupling mission's two identical orbiting observatories will clarify the complex variability and structure in near-Earth plasma driven by lower atmospheric wave energy.	2, 4
	The Geospace Dynamics Constellation will provide the first simultaneous, multipoint observations of how the ionosphere-thermosphere system responds to, and regulates, magnetospheric forcing over local and global scales.	2, 4

Possible new start this decade given budget augmentation and/or cost reduction in other missions	The Magnetosphere Energetics, Dynamics, and Ionospheric Coupling Investigation will target complex, coupled, and interconnected multi-scale behavior of the magnetosphere-ionosphere system by providing global, high-resolution, continuous three-dimensional images and multi-point in situ measurements of the ring current, plasmasphere, aurora, and ionospheric-thermospheric dynamics.	2, 4

Chairman PALAZZO. Thank you, Dr. Baker.

I now recognize our next witness, Mr. Charles Gay, for five minutes to present his testimony.

STATEMENT OF MR. CHARLES J. GAY, DEPUTY ASSOCIATE ADMINISTRATOR, SCIENCE MISSION DIRECTORATE, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. GAY. Thank you. Mr. Chairman and Members of the Subcommittee, thank you for the opportunity to discuss NASA's heliophysics program, and in particular, NASA's response to the heliophysics decadal survey released in August of 2012.

NASA's heliophysics program studies, the Sun, the Earth's near-space environment and the heliosphere, the region created by the solar wind that forms the boundary of our solar system. By studying this interconnected system, NASA provides understanding of the fundamental space processes that occur throughout the university and drive our connected Sun-Earth system.

NASA currently operates 18 heliophysics missions that can be thought of as a single observatory: the Heliophysics System Observatory, or HSO. The HSO has produced a number of scientific discoveries over the last year alone. Voyager has taken us to the edge of the solar system, and many believe they will leave the solar system and reach interstellar space within the next decade. The twin STEREO spacecraft have allowed us to view space weather events throughout the solar system, and the recently launched Van Allen probes are already making new discoveries about Earth's radiation belts.

In addition, NASA continues to develop important new missions to support the Heliophysics Research program: the IRIS explorer mission, launching next spring, the Magnetosphere Multiscale Mission, launching in 2015, the Solar Orbiter, a collaboration with European Space Agency, planned for launch in 2017, and Solar Probe Plus in 2018.

NASA is pleased to receive the heliophysics decadal survey and plans to work towards accomplishing the recommendations for our science program. As its top priority, the survey endorses NASA's current program of missions in development. The second priority is the DRIVE initiative that Dr. Baker mentioned. Its goal is to optimize the scientific return of current and future missions by establishing a healthy research environment and to also enable future missions through technology enhancements.

The next priority is the acceleration and expansion of the Heliophysics Explorer program. The Explorer program has a long history of returning focused, cutting-edge science and providing tremendous value to this Nation. The decadal committee recognized that we are operating in times of flat budgets and understood that the modest increases for DRIVE and Explorer would be achieved through a gradual rebalance of this portfolio.

The survey then prioritized the science targets for four recommended missions in the Solar Terrestrial Probes program and the Living With a Star program. NASA appreciates the flexible nature of this recommendation. By providing science targets and leaving the detailed implementation to NASA, we can ensure that these missions are guided by the latest science and enabled by the latest technologies. Furthermore, the decision rules embedded within the survey will allow us to ensure that the highest priorities will be addressed.

In addition to the heliophysics science recommendations, the survey also made recommendations related to space weather applications that are addressed collectively to the relevant government agencies. NASA recognizes the importance of the recommendations and will continue collaborating with other agencies. However, as the survey acknowledges, these separate space weather recommendations are above and beyond current funding resources. NASA and NOAA currently work together and with other government agencies on satellite development, operations, data processing, and modeling to inform space weather predictions. NASA performs research that leads to improved space weather prediction models and works with NOAA to transition these research results to operations. NASA has also committed to supporting its part of the National Space Weather program, a federal interagency initiative established to improve coordination on space weather activities.

I would like to express my appreciation to the survey Chairs, Dr. Dan Baker and Dr. Thomas Zurbuchen, and to the many volunteers and staff who worked tirelessly to develop this decadal survey. They have provided an effective guide for NASA to pursue the highest-priority science in heliophysics over the next decade.

Mr. Chairman and Members of the Subcommittee, I appreciate your support of NASA's heliophysics program and the opportunity to appear here today. I would be pleased to respond to your questions. Thank you.

[The prepared statement of Mr. Gay follows:]

HOLD FOR RELEASE
UNTIL PRESENTED
BY WITNESS
November 28, 2012

Statement of
Charles Gay
Deputy Associate Administrator, Science Mission Directorate
National Aeronautics and Space Administration
before the
Subcommittee on Space and Aeronautics
Committee on Science, Space and Technology
U.S. House of Representatives

Mr. Chairman and Members of the Subcommittee, thank you for the opportunity to discuss the accomplishments, status, and future direction of NASA's Heliophysics program and, in particular, NASA's response to the Heliophysics decadal survey, "*Solar and Space Physics: A Science for a Technological Society*," released in August 2012.

NASA's Heliophysics program studies the Sun, Earth's near-space environment, and the heliosphere (the magnetic bubble created from the Sun's energy output and inflated by the solar wind that contains our solar system) as an inter-connected system. By studying this system, NASA provides understanding of the fundamental space processes that occur throughout the universe and that drive our Sun-Earth connection.

Our ability to understand the Sun-Earth system is of growing importance to our Nation's economic well-being and security. The Sun is highly variable and produces geomagnetic storms and space weather (i.e., conditions on the Sun, the solar wind, and atmosphere that affect Earth's electromagnetic environment). Geomagnetic storms and the ensuing space weather effects are phenomena that can disrupt communications, navigation, satellite operations, and electric power distribution; a severe geomagnetic storm has the potential to cause significant socioeconomic loss as well as impacts to national security. Furthermore, space weather impacts can be seen throughout the solar system and the emerging science of interplanetary space weather forecasting is crucial to NASA's human and robotic exploration objectives beyond Earth's orbit.

Our program seeks answers to the following questions: What causes the Sun to vary? How do Earth and the heliosphere respond? What are the impacts on humanity?

The Role of Decadal Surveys

NASA uses the recommendations of the National Academy of Sciences' decadal surveys for guidance in planning the future of its science program. Decadal surveys have proven indispensable in establishing a broad national science community consensus on the state of the science, the highest priority science questions to be addressed, and actions that could be taken to address those priority science topics. NASA contracts with the Academy to prepare decadal surveys in all four science areas of NASA's Science Mission Directorate: Astrophysics, Earth Science, Heliophysics, and Planetary Science. NASA uses survey recommendations to set science priorities for its programs. These priorities are used not only for planning the flight program, but also for prioritizing technology development and evaluating proposals for theoretical and suborbital supporting research. The survey's science-based recommendations for flight missions are adapted to yearly budgets, technological capabilities, national policy, partnership opportunities, and other programmatic factors. Recently, the Academy has expanded its decadal survey portfolio to include its first decadal survey in the area of life and physical sciences investments.

The first Heliophysics decadal survey was published in 2003 and covered the period from 2003 to 2012. NASA's Heliophysics Division accomplished all of the NASA top-priority recommendations in the 2003 Decadal Survey of Solar and Space Physics in each of the four categories (Large/Moderate/Small Missions and Vitality of the Research Program). Implementation of the recommendations from that survey brought important changes to the field of solar and space physics. The field advanced from studying separate phenomena to an integrated research strategy whereby significant gains in understanding came through considering the investigations as interacting parts of a complex system. We are now able to track the evolution of solar events from the solar interior to the surface of Earth, connecting the magnetized structure in the Sun's corona to the detailed features of Earth-directed coronal mass ejections (CMEs), to the intricate anatomy of geomagnetic storms as they impact Earth two to three days later. Perhaps the most significant advance is what we have learned about the impact of these geomagnetic storms on society in terms of disrupting satellite operations and electric power grids. The 2003 survey made the study of space weather a high priority and forever changed our view of how interconnected our lives can be with our star, the Sun.

NASA found the recommendations of the previous decadal survey for this field to be invaluable. We anticipate even greater advances through this new decadal survey.

Recent Accomplishments and Current Missions

Today, NASA's Heliophysics flight missions are operated as a single observatory, the Heliophysics System Observatory (HSO).

Over the past year, the HSO produced a number of scientific discoveries.

- Using Solar Dynamics Observatory data, scientists shed new light on the question of how and when solar eruptions occur. They also discovered that the total energy from the extended phase of a solar flare event can supply more energy into the Earth system than the initial, highly visible phase of the flare.
- The Aeronomy of Ice in the Mesosphere (AIM) mission team has classified a wide range of ice structures in polar mesospheric clouds, some never seen before, to help us understand the complex structure of Earth's upper atmosphere and how it is affected by the Sun's processes and how it interacts with the lower atmosphere where we live. Some features show commonality with tropospheric clouds implying that similar processes are occurring.
- Voyager 1 has entered the previously unexplored region between our solar system and interstellar space where the wind of charged particles streaming out from our Sun has calmed and our solar system's magnetic field has piled up. The Voyagers are poised to provide the first ever measurements of the environment that envelop and govern our solar system.

- Thermosphere, Ionosphere, Mesosphere Energetics and Dynamics (TIMED) data collected over the last solar cycle (~11 years) has resulted in the creation of a new understanding of how the Earth's upper atmosphere, thermosphere, mesosphere, and ionosphere respond to changes in the Sun.
- Scientists studying Time History of Events and Macroscale Interactions during Substorms (THEMIS) mission data discovered that particles escape Earth's radiation belts by streaming out into space, in addition to raining down into Earth's atmosphere.
- STEREO has shown the value of using multiple vantage points to forecast the impact of solar storms and their impact on our Earth system. STEREO observations provide essential insights into the structure of coronal mass ejections (CMEs) and the distribution of the most hazardous solar particles as they traverse interplanetary space.
- Interstellar Boundary Explorer (IBEX) and Two Wide-angle Imaging Neutral-atom Spectrometers (TWINS) gave the best ever global picture of the evolution of near-Earth geomagnetic storms, especially of the processes by which the Sun injects energy into the magnetosphere to induce these storms, which will help us determine the path by which the extra energy is dissipated, including any effects on Earth.
- Hinode and the Solar and Heliospheric Observatory (SOHO) missions discovered that the evolution of the Sun's internal magnetic dynamo is not as uniform as has been assumed. That is, as the solar cycle unfolds every 11 years, the regular "flip" of the magnetic north and south poles of the Sun can be asymmetrical rather than simultaneous. Understanding the evolution of the Sun's intrinsic magnetic field is essential to the prediction of solar activity cycles and the ability to model and predict significant solar storms.

Collectively, these missions are an extremely valuable resource. We are able to observe the origins of solar flares and CMEs, we are able to study how these events evolve in transit through the solar system, and we are able to monitor the effects of the events as they engulf Earth and other key locations in the solar system. Several of these research satellites have become an essential part of our Nation's space weather prediction system. The capabilities are, in large part, what the previous solar and space physics decadal survey recommended and the accomplishments are points of pride for all involved. NASA undertook significant technical challenges to deploy this Sun to Earth observing system and accomplished a great deal toward what was once only aspiration. The benefit to the Nation has been significant.

NASA continues to develop new missions to support the heliophysics science program. Completion of the missions currently in development, cited as the top priority of this new Heliophysics decadal survey, will fill key gaps in the Heliophysics System Observatory and enable new scientific discovery in the field of Heliophysics.

- Launched in August 2012 and transitioned into routine operations in October, the Van Allen Probes mission, (formerly the Radiation Belt Storm Probe or RBSP mission), along with the related Balloon Array for RBSP Relativistic Electron Losses (BARREL) balloon flights will help us understand the Sun's influence on Earth and near-Earth space by studying the Earth's radiation belts. During periods of intense space weather, the density and energy of radiation belt particles can increase significantly posing a danger to astronauts and spacecraft that fly through these regions.
- Interface Region Imaging Spectrograph (IRIS), the next Explorer-class mission launching in early 2013, will increase our understanding of energy transport through the solar atmosphere into the corona and solar wind and provide an archetype for all stellar atmospheres.
- Magnetospheric Multiscale (MMS), which will launch in 2015, will use Earth's magnetosphere as a laboratory to study the microphysics of three fundamental plasma

processes: magnetic reconnection, energetic particle acceleration, and turbulence, all of which play key roles in space weather.

- Solar Orbiter Collaboration (SOC) is a European Space Agency-NASA partnership that will continue NASA's solar wind observations and that will address a central question of heliophysics: How does the Sun create and control the heliosphere? It is scheduled to launch in 2017.
- Solar Probe Plus (SPP) has been a top priority of the heliophysics science community for decades and will make the first visit to the solar corona about 3 months after launch to discover how the corona is heated, how the solar wind is accelerated, and how the Sun accelerates particles to high energy. Technically very challenging, this mission will be about eight times closer to the Sun than any spacecraft has come before (coming as close as 3.7 million miles) enduring 2600-degrees Fahrenheit, supersonic solar particles, and intense solar radiation. It is scheduled to launch in 2018.
- The next Explorer-class mission will be selected in spring 2013 from several concepts currently under study. At that time, NASA will choose one full mission for flight and potentially one mission of opportunity. The selected mission will continue the scientific discoveries that enable full understanding of our Sun and its interactions with the Earth and the solar system.

Planning the Future of Heliophysics –The 2012 Decadal Survey

Over a two-year period, several hundred people from the Heliophysics community worked to outline the highest priority science investigations for NASA to pursue over the next decade. NASA would like to express its appreciation to the survey Chairs, Dr. Daniel Baker and Dr. Thomas Zurbuchen, and to the many volunteers and staff who worked tirelessly to bring this effort to a successful conclusion.

The survey has been well received at NASA and has features that make it an effective guide for NASA's planning over the next decade.

- First, the scientific program recommended would significantly improve our understanding of the Sun-Earth-Heliosphere system; the survey specifically targets areas for which observations and understanding do not currently exist.
- Second, the survey recommended a realistic program for NASA's portion of the survey. The top priorities require only modest investments with the potential for immediate rewards. In addition, the survey includes Decision Rules that can be applied if resources are substantially different than projected. The Decision Rules preserve balanced progress across the sub-disciplines and minimize disruption of the highest-priority targets for advancement.
- Last, the program recommended can significantly advance our Nation's capability to provide space weather data and information for severe events and NASA appreciates the emphasis on inter-agency cooperation.

The decadal survey has five main recommendations that are listed below in priority order as designated in the decadal survey, and two applications-related recommendations. The survey's first recommendation is,

> **R0.0: Baseline Priority for NASA and NSF: Complete the Current Program:** *"The survey committee's recommended program for NSF and NASA assumes continued support in the near term for the key existing program elements that constitute the*

Heliophysics Systems Observatory (HSO) and successful implementation of programs in advanced stages of development."

The decadal survey endorses NASA's current program of missions in development and formulation. At the time of the survey, the current program included the Van Allen Probes mission, that successfully launched on August 30, 2012, BARREL, IRIS, MMS, SOC, and SPP missions. Each of these missions is fully funded in the President's FY 2013 budget request to Congress.

The survey's second recommendation is,

> **R1.0 Implement the DRIVE Initiative:** *"The survey committee recommends implementation of a new, integrated, multiagency initiative (DRIVE—Diversify, Realize, Integrate, Venture, Educate) that will develop more fully and employ more effectively the many experimental and theoretical assets at NASA, NSF, and other agencies."*

The decadal survey made specific recommendations for augmenting NASA's Heliophysics operating missions, research grants programs, technology development, and low-cost access to space (LCAS) program. For the survey's DRIVE recommendations, NASA will complete the following studies, and, in consultation with its advisory groups, use the study findings to set program-level policies to best fulfill the survey's recommendations.

- NASA will conduct a study on the budget implications of setting aside competed research funding equal to 2% of each mission's life cycle costs for dedicated guest investigator programs.
- While continuing the current level of support for laboratory plasma astrophysics and spectroscopy investigations, NASA will open discussions with NSF and the Department of Energy (DOE) on the possibility of a jointly competed program in this area.
- NASA will open a joint study with NSF and other agencies to explore methods by which data from space- and ground-based observatories could be combined and utilized to maximize their potential to address larger-scale, Sun-Earth system scientific questions.
- NASA and NSF have recently demonstrated the value of jointly funded, larger-scale scientific investigations, commonly called "strategic capabilities", and NASA intends to continue supporting these partnerships when it is possible to do so. NASA believes it should be possible to extend this successful model to the solicitation and support of multidisciplinary teams that tackle high priority, grand scientific challenges as recommended in the survey.

The survey's third recommendation is,

> **R2.0 Accelerate and Expand the Heliophysics Explorer Program:** *"The survey committee recommends that NASA accelerate and expand the Heliophysics Explorer program, the most successful and impactful mission line in the Heliophysics program. The survey committee recommends that the current Heliophysics Explorer program budget be augmented by $70 million per year, in fiscal year 2012 dollars, restoring the option of Mid-size Explorer (MIDEX) missions and allowing them to be offered alternatively with Small Explorer (SMEX) missions every 2 to 3 years. The survey committee recommends that, as part of the augmented Explorer program, NASA should support regular selections of Missions of Opportunity, which will allow the research community to quickly respond to opportunities and leverage limited resources with interagency, international, and commercial partners."*

The Explorer program has a long history of returning cutting edge science and provides tremendous value to Heliophysics science. In fact, our Nation's first mission to space, Explorer 1, discovered the Earth's radiation belts and opened the field of space-based Heliophysics observations. The Explorer program continues today, providing frequent flight opportunities for world-class scientific investigations addressing heliophysics and astrophysics space science goals.

This recommendation is in-line with NASA's aspirations for the Explorer program. NASA will strive, budget allowing, to achieve the 24 to 36-month period between Explorer Announcements of Opportunity (AOs) although it will take a few years before this is established. Specifically, the next AO for a Heliophysics Explorer may not be feasible until 36 months after the current Explorer selections to be announced in spring 2013 (~52 months since the last AO came out) due to the Explorer budget. The only barrier to offering a MIDEX-size mission will be the availability of an appropriately priced launch vehicle.

The survey's next two recommendations are for the Solar Terrestrial Probes (STP) program and the Living with a Star (LWS) program,

> **R3.0: Solar Terrestrial Probes**: *"The survey committee recommends that NASA's Solar-Terrestrial Probes program be restructured as a moderate-scale, competed, principal-investigator-led (PI-led) mission line that is cost-capped at $520 million per mission in fiscal year 2012 dollars including full life-cycle costs."*
> and,
> **R4.0: Implement a large Living With a Star (LWS) mission to study the ionosphere-thermosphere-mesosphere system in an integrated fashion:** *"The survey committee recommends that, following the launch of RBSP and SPP, the next LWS science target focuses on how Earth's atmosphere absorbs solar wind energy."*

NASA concurs with the science priorities for the four recommended missions. Some of these missions will likely not launch in the decadal timeframe, however, NASA should be able to initiate formulation or pre-formulation activities for the majority of the missions within the decadal timeframe.

In addition, NASA appreciates the flexible nature of the survey's mission recommendations – by providing science targets and leaving the detailed implementation for the procurement phase, NASA can ensure that these missions are enabled by the latest technologies

For the three STP missions, SMD will endeavor to formulate them as moderate-scale, approximately $520M cost-capped missions with the mission requirements, capabilities, and designs consistent with this cost target. NASA intends to study further whether these missions should be "PI-led" in the same manner as for Explorer or Discovery Program missions.

Heliophysics and Space Weather

The Sun's influence is wielded through its gravity, radiation, solar wind, and magnetic fields, all of which interact with the gravity, magnetic field, and the extended atmosphere of the Earth and other solar system bodies to produce geomagnetic storms and space weather. Space weather refers to the conditions on the Sun and in the solar wind, magnetosphere, ionosphere, and thermosphere, which can cause disruption to satellite operations, communications, navigation, and electric power distribution grids; a severe geomagnetic storm has the potential to cause significant socioeconomic loss as well as impacts to national security.

Given the growing importance of space to our Nation's economic well-being and security, it is of increasing importance that NASA and its partner agencies continue to advance our Nation's capability to understand and predict space weather events. NASA, NSF, the National Oceanic and Atmospheric Administration (NOAA), the Department of the Interior, and the Department of Defense developed the satellites and models currently in use to predict space weather effects. Specifically, NASA and NOAA work together (with other government agencies) on satellite development, operations, data processing, and modeling that inform and improve space weather predictions. Together, much has been accomplished to advance understanding of the Sun-Earth system. However, much research and development remains to be done.

The decadal survey went beyond its Heliophysics science recommendations and also made recommendations related to space weather applications that are addressed collectively to the relevant government agencies. NASA recognizes the importance of the recommendations and will continue collaborating with other agencies to realize the decadal survey recommendations. However, as the survey acknowledges, these separate, space weather recommendations are above and beyond current funding resources for the foreseeable future and will most likely not be fulfilled in the decadal survey timeframe.

NASA intends to continue supporting solar, solar wind, and near-Earth environment observations that are essential for space weather prediction efforts and for the transition of NASA's research into NOAA's space weather operations. NASA and NOAA recently agreed to improve coordination, including expediting communications concerning space weather cooperation during major solar events and having periodic meetings with program managers and scientists to identify lessons learned and make adjustments as needed. NASA is committed to supporting its part of the National Space Weather Program (NSWP), a federal interagency initiative established to improve the Nation's capability to make timely and reliable predictions of significant disturbances in space weather, and to help protect critical societal infrastructure, including communication, navigation, and terrestrial meteorological spacecraft. NASA's responsibility is to understand the space environment and the causes of potential hazards for the benefit of society and for securing human and robotic space travel across the solar system.

Summary

NASA implements a research program to understand the Sun, its interactions with the Earth, and how these phenomena impact life and society. NASA researches and develops new mission and instrument capabilities in this area, providing new physics-based algorithms to advance the state of solar physics, space physics, and space weather modeling. This research program is conducted in partnership with other domestic and international research programs to maximize efficiencies and progress.

NASA is pleased with the results of the heliophysics decadal survey and plans to work towards accomplishing the priorities of the scientific community in a timely manner. In particular, the enhancement of the Explorers program is important to utilize the full potential of the heliophysics community toward meeting our national goal of understanding the space environment. The DRIVE program will optimize the scientific return of current and future missions by establishing a healthy research environment and will also enable future missions through its technology enhancements.

Although budget constraints present challenges to the implementation of the survey, the Decision Rules embedded with the survey provide valuable information to ensure the highest priority efforts are completed. NASA is in the process of utilizing the decadal survey recommendations to form the basis for a NASA Heliophysics science and technology strategic plan. This plan for addressing the Heliophysics decadal survey recommendations will be detailed as part of the President's FY 2015 budget request.

Mr. Chairman and Members of the Subcommittee, I appreciate your support of NASA's Heliophysics program. I would be pleased to respond to any questions you or the other Members of the Subcommittee may have.

Chairman PALAZZO. Thank you, Mr. Gay.

I now recognize our final witness, Ms. Laura Furgione, for five minutes to present her testimony.

STATEMENT OF MS. LAURA FURGIONE, ACTING ASSISTANT ADMINISTRATOR FOR WEATHER SERVICES, AND ACTING DIRECTOR, NATIONAL WEATHER SERVICE, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Ms. FURGIONE. Good morning, Mr. Chairman and Members of the Committee. My name is Laura Furgione, and I am the Acting Director of the National Weather Service in NOAA. Thank you for the opportunity to testify today about space weather.

While probably best known for our role in hurricane, tsunami, flood and tornado forecasts and warnings, NOAA also has operational responsibilities for space weather forecasts and warnings. NOAA is the U.S. government's official and definitive source of civilian space weather forecasts, warnings and alerts for the general public, industry and government agencies. The NOAA Space Weather Prediction Center, commonly called SWPC, operates 24 hours a day, providing real-time forecasts and warnings of solar and geophysical events to a society that is increasing its reliance on technology vulnerable to the impacts from space weather.

Recognizing the importance of 24/7 forecasts and warnings, in 2005, NOAA transferred its space weather prediction program from an applied research environment to our operational environment. NOAA geostationary spacecraft provide critical observations of solar and geophysical events for NOAA's space weather forecasts used by thousands of customers worldwide including the Department of Defense, NASA, satellite companies and airlines, as you said. In fact, 80 percent of the DOD space weather alerts and warnings rely on GOES data. Currently, NOAA polar satellites include the space environment monitor, which is a suite of instruments that measure energetic particles in the lower Earth orbit which may impact communications, satellite operations, radar systems, and the International Space Station. SWPC also uses data from the NASA Advanced Composition Explorer, or ACE satellite, to issue warnings on geomagnetic storms. ACE was launched in 1997 with a two-year design life and as a single point of failure for these critical measurements. SWPC also relies on the chronograph data from the Solar and Heliophysics Observatory and the Solar-Terrestrial Relations Observatory Missions to see coronal mass ejections, or CMEs, that erupt from the Sun, allowing NOAA to issue geomagnetic storm watches, which provide 1- to 3-day advance notice of a geomagnetic storm.

There are extensive interagency interactions and planning already underway to ensure continuity of solar wind data and CME detection. NOAA is working with NASA to refurbish the Deep Space Climate Observatory, or the DSCOVR spacecraft, to provide space weather measurements from the L1 position, which is between the Sun and the Earth, about a million miles upstream. Data from this location provide 1 hour of warning for a geomagnetic storm that will impact the Earth affecting the electric power grid, satellites, GPS, radio communications and other systems, as mentioned. NOAA and the Air Force have been appropriated funding to refurbish, launch and operate the DSCOVR satellite to provide continuity of solar wind measurements as well as CME. NOAA is also working to incorporate cutting-edge technology under development at NASA. NOAA will continue interagency and international partnerships as well as the use of commercial services to meet these data requirements.

SWPC maintains a close working relationship with its user community and adjusts its products and services to meet the growing and changing needs of these customers. Through this interaction, NOAA identifies operational data requirements and space weather model requirements, which are made available to NASA, NSF and the broader research community. NOAA transitioned this research into operations as efficiently and effectively as possible.

In 2011, NOAA successfully transitioned the first-ever physics-based space weather prediction model into operational use. This model was largely developed by NSF and transitioned into research into operations from NASA. This model helps forecasters understand when an eruption on the Sun may impact the Earth and result in a geomagnetic storm.

The NRC decadal survey report emphasizes the importance of space weather for society and therefore the value of work conducted by NOAA to provide services that protect life, property and enhance the economy. This report sets dates for NOAA to continue fulfilling its critical leadership role in space weather operations and applying forecasts and services to the benefit of society. As the agency responsible for integrating research into operations, NOAA looks forward to working with our federal partners to ensure the latest successful research is available and to be transitioned.

The report states, "It is critical that we develop predictive capabilities for space weather events while maintaining comprehensive measurements for now casting solar wind, energetic particle inputs into geospace." We must ensure operational needs continue to be met. The report also discusses distribution of essential operational data. NOAA believes that as the operational agency, it should continue to distribute these observations.

Our Nation remains vulnerable to space weather and needs more timely and accurate forecasts to help mitigate the potential impacts. The NRC report is an excellent first step and identifies critical research activities that are necessary to expand our comprehensive understanding of space weather as well as improve our Nation's forecast and warning capability. The Nation requires ongoing research and development that will inform operations. As such, NASA, NSF and the academic community conduct important research and development activities that NOAA can access for its operations. The NRC report has provided critical insight into the areas that the larger space weather community and the agencies will continue to assess in the years to come.

Thank you very much for your time and the opportunity to comment today.

[The prepared statement of Ms. Furgione follows:]

WRITTEN STATEMENT BY
LAURA K. FURGIONE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

ON THE
NATIONAL PRIORITIES FOR SOLAR AND SPACE PHYSICS RESEARCH AND APPLICATIONS FOR SPACE WEATHER PREDICTION

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

NOVEMBER 28, 2012

Introduction

Good morning Mr. Chairman and Members of the Committee. My name is Laura Furgione and I am the Acting Director of the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) in the Department of Commerce. Thank you for the opportunity to testify at this hearing about space weather.

NOAA plays a critical role to ensure our Nation is warned of natural hazards and prepared to respond should such an event occur. While probably best known for our role in hurricane, flood, and tornado forecasts and warnings, NOAA also has operational responsibilities for space weather forecasts and warnings. Today I will discuss how NOAA integrates National Aeronautics and Space Administration (NASA) research and observations and National Science Foundation (NSF) funded research into operations and then focus my testimony on NOAA's efforts to predict space weather impacts for the Nation and the world, in the context of the 2012 National Research Council (NRC) report, "Solar and Space Physics: A Science for a Technological Society."

NOAA is the U.S. Government official and definitive source of civilian space weather forecasts, warnings, and alerts to the general public, industry, and government agencies. The NOAA Space Weather Prediction Center (SWPC), which is one of nine national environmental prediction centers within the NWS, has a mission to deliver space weather products and services that meet the evolving needs of the Nation. SWPC operates 24 hours a day, 7 days a week (24x7), and provides real-time forecasts and warnings of solar and geophysical events. This is becoming even more important as our society increases its reliance on technology that is vulnerable to the impacts from space weather.

Critical Observations

NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) operates the Geostationary Operational Environmental Satellite (GOES) and Polar-orbiting Operational Environmental Satellite (POES) spacecraft, which provide critical observations of solar and geophysical events that are incorporated into NOAA's forecasts and satellite anomaly assessments for use by the Nation. The NOAA GOES spacecraft provides critical data in support of our Nation's technological infrastructure. Indeed, multiple activities associated with our industry, economic, and defense sectors depend on our ability to monitor and predict the space environment using critical measurements from GOES. NOAA issues space weather alerts, warnings, and forecasts using GOES data to thousands of customers worldwide, including airlines, satellite companies, NASA, and the Department of Defense (DoD). In fact, 80% of DoD space weather alerts and warning rely on GOES data. The GOES-R series satellites, NOAA's next generation geostationary satellites, will continue and extend space environment measurements begun almost forty years ago. GOES-R will introduce new solar imagery capability, and an expanded range of energetic particle measurements, that will improve our products and meet growing national needs for space weather services.

NOAA POES satellites include the Space Environment Monitor (SEM) - a suite of instruments that measure energetic particles in lower Earth orbit. The SEM provides measurements of Earth's radiation belts and the increases of charged particles associated with solar eruptions. This information has long been used to assess space weather impacts on communications, satellites operations, radar systems, and the International Space Station.

NOAA is currently working with NASA to refurbish the Deep Space Climate Observatory (DSCOVR) spacecraft to provide space weather measurements from the L-1 position which is between the Sun and the Earth, 1 million miles upstream of Earth. A satellite at this L-1 position provides approximately one hour of warning for a space weather event that will impact Earth. When these space weather events impact Earth, they cause geomagnetic storms which can result in significant electric power grid problems. Satellites, airlines, GPS, radio communications, and other systems can be seriously affected as well.

NOAA's National Geophysical Data Center provides scientific stewardship of NOAA's space weather data. They are responsible for the archive and access of operational solar and space environmental data and derived products collected by NOAA and DoD observing systems.

NOAA also uses data from several NASA research satellites to augment its warnings and forecasts. SWPC uses data from the Advanced Composition Explorer (ACE) satellite to issue warnings on geomagnetic storms. ACE was launched in 1997 with a 2-year design life and is a single point of failure for these critical measurements. SWPC also relies on the coronagraph data from the Solar and Heliospheric Observatory and the Solar Terrestrial Relations Observatory missions to see coronal mass ejections (CMEs) erupt from the Sun, allowing NOAA to issue geomagnetic storm watches, which provide 1-3 day advance notice of a geomagnetic storm. These critical observations also provide the initial input to geomagnetic storm forecast prediction models.

Research to Operations

NOAA has extensive experience transitioning research to operations, best illustrated by the NOAA hurricane program. In this instance, NOAA research and development activities work hand in glove with operations staff to define requirements for improvement and develop new techniques and models, which are then evaluated in a test-bed environment before adjustments are made and finally implemented into operations. NOAA uses a similar process to bring space weather research to operations. NOAA defines operational data requirements and space weather prediction model requirements, which are made available to NASA and the broader research community. NASA develops new space weather prediction models, and NOAA transitions NASA research into operations as efficiently and effectively as possible. NASA works with NOAA to define needs and requirements, develops models in conjunction with partners in academia, and assists as NOAA integrates the model into operations. In 2011, NOAA successfully transitioned the first physics-based space weather prediction model into operational use. This model was largely developed by NSF funded research and transitioned into operations from NASA. This model helps forecasters understand when an eruption on the Sun may impact Earth and result in a geomagnetic storm.

SWPC maintains a close working relationship with its user community and adjusts its products and services to meet the growing and changing needs of its customers, including emergency responders, power grid, satellite, aviation, and GPS industries. As new requirements are defined by the user community, SWPC works to develop products and services to meet those needs, and works with NASA and the broader research community to ensure SWPC requirements are met.

Recognizing the importance of 24x7 forecast and warnings, in 2005, NOAA transferred its space weather prediction program from an applied research environment into NWS operations. NOAA believes that NASA provides important research capabilities that, once proven, could be useful to NOAA's operational mission. As I will discuss later, the NRC report calls for NOAA to re-establish and support applied research efforts in space weather. NOAA and NASA have distinct roles in the national space weather program with NASA focused on research and NOAA on forecasts, operations, and applied research. NASA provides its experimental data to NOAA to be incorporated into operational space weather predictions.

There are extensive interagency actions and planning already underway to ensure continuity of solar wind data. NOAA and the Air Force have been appropriated funding to refurbish, launch, and operate the DSCOVR satellite to provide continuity of solar wind measurements after the ACE research satellite fails. This option was developed consistent with the recommendations of the nineteen-agency review which was conducted under the auspices of the Office of the Federal Coordinator for Meteorology at the request of the Office of Science and Technology Policy. This review recommended that NOAA, NASA, and the Air Force collaborate to refurbish and launch DSCOVR. NOAA and Air Force have received appropriations and work is underway. NOAA, in consultation with its operational partner, the Air Force, is assessing plans for continuity of such data after DSCOVR. We are evaluating the best value options for continuity for our requirements for solar wind observations and the initiation of operational coronal mass ejection imagery in the post-DSCOVR era. We will consider interagency and international partnerships as well as the use of commercial services to meet these requirements. NOAA will focus on operational space weather observations needed to meet operational forecasting requirements.

Decadal Survey Report

The NRC Decadal Survey report emphasizes the importance of space weather for society and therefore the value of the work conducted by NOAA to provide services that protect life and property and to provide economic benefits for the Nation. The report's number one science goal for the next decade is to "determine the origins of the Sun's activity and predict the variations in the space environment." Promoting NASA and National Science Foundation (NSF) research programs in directions that will lead to improving space weather predictive capabilities will ultimately benefit NOAA's ability to provide the Nation with improved services. This report sets the stage for NOAA to continue fulfilling its critical leadership role in space weather operations and applying forecasts and services to benefit society.

The report provides an excellent assessment of the state of heliophysics and provides a roadmap for moving NASA into the next decade. The importance of space weather is highlighted throughout the document and many of the proposed missions and research that are highlighted would provide key information for improving modeling and forecasts. As emphasized in the report, it is important that space environment research and data be transitioned to operations. The multi-agency effort required to accomplish research to operations is well recognized and the report calls for more resources to take full advantage of current research. Furthermore, the report recommended several times that NOAA should increase its internal applied space weather research capability to enhance the research to operations activities.

The survey highlights NOAA's role in operational forecasts to support society and civilian customers. The importance of NOAA observations in supporting the operational needs of customers is also clearly stated. NOAA and NASA are currently updating roles and responsibilities regarding space weather programs.

This report contains many pertinent recommendations for the National Space Weather Program which is a coordinating program involving numerous Federal agencies. Below are NOAA's views of the recommendations that affect our operational space weather forecast mission.

The report identifies the need for NOAA to establish a space weather research program to effectively transition research to operations. Before SWPC was transferred to the NWS in 2005, there was an applied research program in NOAA's Office of Oceanic and Atmospheric Research. With the transition of SWPC to the NWS, NOAA transitioned its focus to operational space weather forecasting resulting in reduced emphasis on applied research, which is needed to advance operational space weather prediction. NOAA still supports space weather research, including evaluating space weather prediction models for operational use and developing satellite algorithms to take advantage of future satellite observations. The report also states that this will require growing the research programs at NSF, NASA, Air Force Office of Scientific Research, and Office of Naval Research. As the agency responsible for integrating research into operations, NOAA looks forward to working with our federal and non-federal partners to ensure the latest successful research is available to be transitioned.

The report states, "It is critical that we develop predictive capabilities for space-weather events while maintaining comprehensive measurements for nowcasting solar-wind and energetic-particle inputs into geospace" (motivation M2 in the report). The report provides a plan for a NASA Heliophysics Systems Observatory. While we agree these types of observations are required to advance our collective understanding of space weather, requirements for "operational" observations are typically not the same as for "research" observations. NASA typically flies sensors that go beyond true operational needs; however, we must ensure operational needs continue to be met.

The report also discusses distribution of essential, operational data. NOAA believes that as the operational agency it should continue to distribute these observations. NOAA currently has the responsibility for distributing operational measurements and should continue in this role.

In general, we also agree that synergy exists between NOAA and NASA and can be enhanced by the space weather community, especially when NASA's research and observing expertise is combined with NOAA's operational expertise and forecast capabilities. However, agency strengths, roles, and responsibilities have not been addressed in the report's recommendation.

Our Nation remains vulnerable to space weather and needs improved forecasts providing more timely and accurate forecasts to help mitigate potential impacts from such events. The NRC report is an excellent first step and identifies critical research activities that are necessary to expand our comprehensive understanding of heliophysics and space weather as well as to improve our nation's forecast and warning capabilities.

In conclusion, the nation requires ongoing research and development that will inform operations. As such, NASA plays an important role to explore new technologies that NOAA can assess for use in its 24x7 operations. The NRC has provided critical insight into the areas that NOAA, NASA, the Department of Defense, and the larger space weather community will continue to assess in years to come.

Chairman PALAZZO. I thank the panel for their testimony. I now recognize myself for five minutes for questions.

Mr. Gay, given the emphasis the survey committee places on maintaining NASA's current portfolio of missions, can you provide us a quick status update on the missions currently in development, particularly the Solar Probe Plus, and what are the greatest risks to cost and schedule at this point in time and how does the current Continuing Resolution impact NASA's ability to keep these missions on track? So about three questions in one.

Mr. GAY. Yes, sir. The quick status of the missions in development, and I mentioned most of them earlier in the oral testimony, the IRIS Explorer mission is on track for a launch in early 2013. The next large mission is the Magnetospheric Multiscale mission on track for launch in 2015, and it is well into development. Basically, we are putting that spacecraft together right now at the Goddard Space Flight Center, and it is undergoing environmental testing very shortly for launch in 2015. The Solar Probe Plus mission is in what we call phase B. It is in its formulation phase. We are doing technology work. We are doing preparations for the critical—the preliminary and the critical design reviews. There are technical challenges there associated with that mission as it is going to come within 9–1/2 solar radii of the Sun so the thermal control systems are one of the greatest challenges there. The spacecraft exterior surfaces will see temperatures in excess of 2,000 degrees Fahrenheit while the electronics will operate at room temperature. The applied physics lab is responsible for implementing that mission, and they have—they are also the organization that successfully launched and operated the Messenger mission to Mercury. So they are used to those hot environments, so we are very optimistic that they have got the thermal control system, you know, well understood here.

The risks to cost and schedule, we are still in the formulation phase for in particular Solar Probe Plus and it has not been confirmed yet where NASA goes through all of the joint conference level cost estimates and independent cost estimates and determines the costs that it will take to implement this mission. That will occur in, I believe, toward the end of 2013, toward the end of next year where we will have that commitment date, and so the risks there are getting through the technology hurdles for the thermal control subsystem solar rays, which are—in this case, they have to be liquid cooled. So those are the things we are watching very closely.

In terms of the effect of the CR, right now we are operating under the 2012 funding levels. Fortunately for heliophysics, that is annualized. When you annualize that, that is really close to the fiscal year 2013 President's budget. So we don't anticipate any problems, at least for the next six months in the heliophysics organization, maintaining its mission on track.

Chairman PALAZZO. Well, thank you, Mr. Gay.

Ms. Furgione, the ACE satellite was launched in 1997 and is currently operating well beyond its planned two-year lifetime while DSCOVR is scheduled to launch in 2014 and is designed for only two years mission life. How does NOAA plan to sustain critical space weather measurements after 2016?

Ms. FURGIONE. Thank you for that question, Mr. Chairman. We already have begun the evaluation of best value operations for continuing NOAA requirements for solar winds and even the initiation of operational CME imagery for the post-DSCOVR era. This will include the role of government agencies as well as the commercial sector and what they could contribute to that post-DSCOVR era.

Chairman PALAZZO. My next question is for all the witnesses. What recommendations do you have to ensure that the Nation maintains continuous space weather measurements and how do we ensure that these measurements do not end up as the next Landsat such that everyone wants the data but no one could afford to pay for the next satellite? Who would like to take that one first? You can rock, paper, scissors for it.

Ms. FURGIONE. I can at least start with your question, Mr. Chairman. One critical component is for the entire space weather enterprise to work together on this and make sure that the government agencies, the commercial sector and also our international partners are a part of this continuous of our space weather—continuous space weather measurements. So that is critical to make sure that we continue communicating across the agencies and with our partners, and the international community has really stepped up so we have some good partnerships there as well.

Mr. GAY. I would add a couple things. One, I think the value that NASA brings is to better understand the fundamental physical processes involved in the way the Sun behaves and the interaction of the Sun with our environment, and the better we understand that phenomenon, the better poised we are to understand space weather, understand—and better able to model and predict. Along the lines of maintaining measurements, heliophysics has a large portfolio of operating missions, 18 currently, and we look at those missions not just as individual phenomena, but look at those missions as they contribute to the broader understanding of the environment, of the space environment, and we have recognized the value in that, and for that reason, we are—as long as these missions are producing valuable scientific information, we want to keep them operating and we have budgeted accordingly. We go through a comprehensive senior review process every two years to look at the operating missions and assess how they are performing, their state of operation, if there is any degradation, are they still contributing to the greater good, and as long as that is true, we are going to keep those spacecraft flying.

Dr. BAKER. And thank you very much for your question. It indicates a sensitivity that I think is very important, and the steering committee for the NRC study was very concerned about your very question, and I think it is crucial that the next steps that we recommended there be taken to look at the posture of the Nation with respect to key observations, modeling tools and so forth that are necessary for an effective 24/7 space weather program into the future. I think it is going to require coordination between the many agencies that are interested in this theme and it is going to take a much more focused effort at high policy levels to assure that we don't have gaps, that we don't have failures to observe the Sun and its effects on the Earth. So this is one of the key things that needs to follow on the decadal survey, in my opinion.

Chairman PALAZZO. Thank you all.

I now recognize Ms. Edwards.

Ms. EDWARDS. Thank you, Mr. Chairman, and thank you to our witnesses.

Mr. Gay, given the uncertainties and the stresses of the current budgetary environment, how is NASA planning to leverage the recommendations in the current survey, and in particular, I was looking at the recommendation around an expanded role for NASA in the post-DSCOVR environment. So if you could respond to that, I would appreciate it.

Mr. GAY. Yes. In terms of the budget stress, fortunately, the decadal committee recognized the environment that we are operating in and the possibility or likelihood of budget stress, and because of that, they did give us some, I think, very good guidance in terms of decision rules of what to do if we are faced with the problems as we work towards implementing the recommendations of the decadal survey, and we do appreciate that very much. They also recognized when they recommended augmentations for Explorer and also for the DRIVE initiative, they recognized that the heliophysics program has a lot in the pipeline right now and those changes, or those enhancements or augmentations would not be realized until sometime downstream when we can rebalance the portfolio gradually.

In terms of the expanded role for space weather, as the survey committee pointed out, the recommendations for an augmented space weather capability were beyond our current scope and funding and also were considered a lower priority than the science program recommendations that they made.

Ms. EDWARDS. Just out of curiosity, though, is the next budget submission intended to incorporate the decadal survey recommendations, even if that is over some period of time?

Mr. GAY. Yes, I believe, beginning in the 2015 budget request, we would begin to see some maybe slight rebalancing but, I mean, our goal would be to achieve that over the next five to ten years.

Ms. EDWARDS. Dr. Baker?

Dr. BAKER. Yeah, I would just like to point out that one of the things we did in the decadal survey was to recommend the IMAP mission. This is the Interstellar Mapping and Acceleration Probe, and this has dual use. It is both a wonderful basic science mission to observe the outer part of the heliosphere but it also would make key solar wind measurements, solar wind measurements that would be a space weather monitoring kind of a tool, so I think there is a great deal we can do to have both basic science and operational capability, and this is just one example of the dual use kind of capabilities we talked about.

Ms. EDWARDS. Thank you.

Ms. Furgione, I am sorry. I mispronounced your name. Ms. Furgione, I wonder if you could tell me about the accuracy of predicting space weather events, because it does seem to me that those are increasingly important in terms of our operation of our critical infrastructure, and in fact every day because we have more infrastructure that is impacted potentially by space weather, and so how good are the—is the current prediction capability and what kinds of improvements can we expect to gain with the implementation of the research recommended in the survey?

Ms. FURGIONE. Thank you, Ms. Edwards. That is one of the components of our operational forecasting scheme is to always validate and verify our forecasts. So we have made significant advancements in the era of when the actual event impacts the Earth. Where we were at 13 hours, our era could be anywhere within a 13-hour window. Now we have reduced that down to a 6-hour window on when we know that the coronal mass ejection will impact the Earth. So that is great strides in improving our forecasts, and also the model that I talked about, the first model that we have been able to operationalize from NSF and NASA, definitely played a critical role in that. So continuing to transition those research into operations is important to advance the forecast accuracy.

Ms. EDWARDS. But it is still not terribly accurate. So, for example, even with a 6-hour window, it is—I mean, it would be really difficult to implement any activity on the ground or protecting the infrastructure in that kind of time frame.

Ms. FURGIONE. So that is a 6-hour window on when it would impact the Earth but the actual alert or warning goes out 1 to 3 days in advance. So you actually do have time in advance to take those precautionary measures on the power grid, on your GPS and on the satellite instruments to put them into safe mode.

Ms. EDWARDS. Thanks.

And then I have 13 seconds. Let me take advantage of that. In your opinion, and this is to any of our panelists, how well do you think the public really understands the linkage between the research and the applications and their everyday experiences of just being able to power on a cell phone?

Dr. BAKER. I would say that there has been tremendous improvement in public awareness of the effects of space weather in, let us say, the last 5 to ten years but we still have a long way to go. We still have a lot of work to do to make people understand what is the variability of the Sun, how does it affect the Earth environment and how does it bore down to their daily lives as your question indicates. I think we have an opportunity with the approaching solar maximum to really see more frequent kind of disturbances, to put those in proper context and to really help the public understand what to be worried about and what not to be worried about. I think it is key that all the agencies play that role.

Ms. FURGIONE. One thing also, as we were looking at the solar maximum and using that as a potential to increase the education and outreach, one of the emphasis is that the solar maximum is an increase in the number of events but not necessarily an increase in the significance of the events. So an event can happen at any time, and we want folks to make sure that they weren't just focusing on the solar maximum and that they were safe before or after the solar maximum because an event can happen at any time.

Chairman PALAZZO. I now recognize Mr. Brooks from Alabama.

Mr. BROOKS. Thank you, Mr. Chairman.

Given the deficits and debt that America has accumulated and the exploding costs of entitlement programs, the two of those putting more and more constraints on the productive side of the federal expenditures, productive being things like NASA and scientific advancement, to what extent should NASA and NOAA consider alternative means for gathering important data via commercial data buys, posted payloads, use of research on the International Space Station, increased use of CubeSats or other means, and that is for any of the witnesses.

Dr. BAKER. I could first remark that thank you for the question, and this was a very important component of our decadal survey was to try to look broadly at all of those alternative means, and I think we came out very strongly foursquare in support of a much greater diversification of access to space, tools in space, rides of opportunity, the data buy service level agreements, all the things you talked about, and I think I can speak with great confidence for the entire steering committee that this was warmly received, these ideas were warmly received within the decadal survey context as excellent ways to make most efficient and effective use of what are known to be limited resources.

Mr. BROOKS. Mr. Gay?

Mr. GAY. Yes, sir. We are looking increasingly at alternative means for access to space, and in fact, most recently have selected a hosted payload in the Earth Sciences Venture Class program. The Tempo mission will be hosted on a commercial geosync spacecraft. Also looking at increased usage of the ISS as a platform for science will be flying the SAGE 3 instrument on the space station, the OKO–3 instrument and also there is some astrophysics missions as well that will be using the space station as a platform. Also, looking at the capabilities for smaller spacecraft to provide real scientific or high scientific results. We are flying CubeSats but more for educational purposes but we are looking at the smaller end. We have a mission that was recently selected called Cygnus, which is multiple small spacecraft that will look at achieving some real groundbreaking science with very small platforms.

Mr. BROOKS. Thank you, Mr. Gay.

Ms. Furgione?

Ms. FURGIONE. Thank you, Mr. Brooks. As I mentioned before, in the post-DSCOVR era, we will definitely have to seek alternative means and look at all the options, particularly in these budget-constrained times.

Mr. BROOKS. Well, I cannot over-emphasize the importance of you all doing whatever you can to become more efficient in the context again of the exploding costs associated with the wealth transfers and the entitlement programs. As you see from the public debate, the issues that we face in Congress are very substantial in that regard, so I appreciate your attentiveness to that issue.

Now, a question for Mr. Baker. What led the survey committee to conclude that the Solar-Terrestrial Probes program would be better suited as competed principal investigator cost-capped missions rather than as a traditional NASA center-led mission?

Dr. BAKER. Yes. We were extremely concerned as a committee and as a community about how to contain the spiraling upward costs in mission development. We worked closely with the aerospace corporation to examine the history of mission performance, and we looked at the question with the aerospace history database, what was the evidence of which missions performed best at a given complexity level, and there was a very clear record in that that showed that PI-led cost-capped missions performed much better at a given complexity level were considerably lower in cost and so it was our considered opinion that making that the hallmark of the Solar-Terrestrial Probes, making them cost capped, making them led by principal investigators, making sure that the full lifecycle costs were going to be contained within that envelope was the single-best way we had of managing them more effectively and in a more cost-contained fashion.

Mr. BROOKS. Thank you, Dr. Baker.

And Mr. Gay, can you please share with us NASA's view on the survey committee's recommendation?

Mr. GAY. Yes, sir. We are certainly going to look at this. I mean, it is an acquisition strategy or acquisition approach, and we have processes at NASA to make these kinds of decisions. We do have to include factors such as workforce. But typically the strategic missions implemented by the NASA centers are traditionally the larger, more complex missions, and it is typically easier to do smaller missions on cost.

That said, however, I believe NASA has been making great strides in our ability to improve our ability to estimate what a mission is going to cost through various analytic tools as well as our ability to manage them with value management and detailed assessments of how things are going, so we have been making improvements, I think really across the board, both on the PI led as well as the in-house missions. I think the idea of looking at the Solar-Terrestrial approach line as a cost-capped mission line is worth considering. In fact, we are going to consider it very closely, and look at models for managing those types of missions so that we can ensure that they are done on cost and on schedule.

Mr. BROOKS. Thank you, and thank you, Mr. Chairman.

Chairman PALAZZO. Thank you, and if there is no objections from the Members, we will enter a second round of questions. Okay, and I will lead off.

Ms. Furgione, does NOAA have any plans to revamp funding for applied space weather research, given its importance as cited in the decadal survey report?

Ms. FURGIONE. Thank you, Mr. Chairman. We were quite excited to see that the report was recognizing that additional resources needed to be dedicated to advancing the development and transition into operations. So as we look at our research activities on applied research, we are definitely hoping to see more connection and more collaboration with NASA and NSF on this research to operations.

Chairman PALAZZO. What are the benefits for rechartering the National Space Weather program as the survey committee recommends versus leaving the program as is, and what are the drawbacks? And this is pretty much for all the witnesses, and we will start off with Dr. Baker.

Dr. BAKER. Yeah, we looked at that. Thank you for the opportunity to talk more about this. It has become clear to us as the steering committee that over the last few years, the National Space Weather program, all its elements have increased in prominence, significance, importance to society, and it was the strong feeling as we discussed these topics that having attention at the highest levels of the executive office of the President would be very valuable, very important and really help to coordinate across the agencies. And so the considered opinion as expressed in the survey was that at least looking seriously at rechartering at a higher level, a higher level within the executive office, making sure that attention was being paid to all the multi-agency issues was probably one of the best ways to increase attention, assure that all the topics and themes were getting their due, and that ultimately we could have a more effective national program.

Mr. GAY. Thank you. I would first say, I would like to have further discussions with Dr. Baker and with NOAA and our other partners in the National Space Weather program council about the pros and cons. I don't feel like I am at a point where I know, you know, or comfortable either way in making a recommendation. But I do know even today under the Office of the Federal Coordinator for Meteorology, we are embarking on development of a strategic plan for that organization, and the principal focus for that is to address the recommendations of the decadal survey. Whether it stays where it is or is rechartered elsewhere, I don't have an opinion on that today, sir.

Chairman PALAZZO. That is fair enough, so you two get together and work it out.

And Ms. Furgione?

Ms. FURGIONE. Thank you, and I have similar comments to that, to my colleagues. It would definitely raise the visibility if that is the primary goal, but we do have quite a few activities that are already underway in our current structure through the National Space Weather Program including, as Mr. Gay talked about, the strategic research plan that is already being developed.

Dr. BAKER. I would just like to say, I would like to compliment the agencies on what they have done with the present advisory and organizational structure. It has been amazing progress in these last years. I would just say that I think it is very worthwhile to talk with the Office of Science and Technology Policy, with the Office of Management and Budget, all the players on the executive side and with strong involvement of the advisory committees and the oversight committees here in Congress to talk about what is the best way to have the most effective national space weather program.

Chairman PALAZZO. All right. Thank you.

Dr. Baker, can you summarize the survey's recommendations related to the new space weather and climatology program with NASA's lead, and what led the committee to make such a recommendation?

Dr. BAKER. Well, first of all, let me say that this was not strictly a recommendation, it was what we call the vision. We—as all good survey committees—overstepped our bounds. We went beyond what we were asked to do or instructed to do, and decided to give advice of a sort where we weren't asked for it. But our vision was to think about what do we need to have an effective national operational space weather program. We have to have complete observations of the Sun, the interplanetary medium, the effects of Earth. We have to have the models, the tools that are really necessary to tie all this together. This really requires an investment of more resources than are presently available in the budgets of any of the agencies, and so the vision we laid out was one that would require another $100 million to $200 per year over this next decade without doing damage to the basic science or the ongoing activities of NOAA or NSF or the other agencies, and so the vision we talked about was if possible, we would love to have the present roles and responsibilities reinforced with more resources, but if that is not possible, then one possible way would be for NASA to take on greater basic observational monitoring of the system, have that put more into its charter and mandate. And so the fundamental recommendation we made was to have a follow-on study that looked closely at these issues and made firm recommendations. We felt the steering committee was neither chartered, as I said, nor did it have the time to do the kind of detailed development of a plan that is really necessary. And so I hope that the real outgrowth of this will not be that we take the vision alone but that we really have a much more detailed examination of all the aspects of this.

Chairman PALAZZO. I now recognize Ms. Edwards.

Ms. EDWARDS. Thank you, Mr. Chairman.

I just want to follow along because I had asked earlier, Mr. Gay, your opinion about expanding NASA's role, but I didn't have a chance to hear from Ms. Furgione about how that expanded role for NASA would relate to NOAA's activities, and so if you could just give me a minute.

Ms. FURGIONE. Thank you, Ms. Edwards, for that question. One of the things with our operational mission is that we are able to rely upon our successes in our hurricane forecasting, and our tornado forecasting, as I mentioned, those particular areas that we have proven success in the past, and that includes with the hurricane model in particular the interagency modeling and the transition to research that we have been able to put in place and improve our hurricane track and intensity forecast. So a proven success, as you saw, with Hurricane Sandy, and so those roles and responsibilities we believe should stay—the operational responsibilities should stay with NOAA in regards to producing those operational forecasts and warnings.

Ms. EDWARDS. So given that, what would you see? As to the extent that NASA were taking on additional areas of responsibility, how would you see that fit in?

Ms. FURGIONE. Well, additional responsibilities, they are already doing the basic and applied research, so if they can continue to work with us on the transition of that applied research through our community modeling, that would be the ideal situation.

Ms. EDWARDS. And so can you just explain to me, and Mr. Gay, perhaps you could chime in here, what are some of the key challenges for transitioning the basic solar and space physics research into tools that can be accessed by users and applied in the operations that Ms. Furgione spoke about?

Mr. GAY. I think some of the key challenges are validation of the models and user acceptance of those models. They do have to go through an extensive validation period, and that is typically a very hard point and takes a lot of time and effort, and I defer to my colleague from NOAA to talk about what is like on the receiving end of those but I am sure it is very difficult for them to, they build confidence in the models that they are operating, using at this time, and there is a high bar, a very high bar for them to accept a new model in that place.

Ms. EDWARDS. Ms. Furgione?

Mr. FURGIONE. Yeah, a point I will make is in regards to our requirements process, so as we look at our customers' requirements and their changing needs and increasing demands for this type of information, that is where we can then hone in on what particular model would ideally help improve our forecasts to meet those customer needs, so it is really about the requirements and also the validation as Mr. Gay talked about.

Ms. EDWARDS. And Dr. Baker, as you respond, I wonder if you could also tell me the degree to which you think that the current federal agency activities that can be coordinated or better coordinated including funding and plans for space weather and how effective the current coordination is.

Dr. BAKER. Let me respond to, or address a point that was just made here. I would say that the difference between terrestrial weather and space weather is the degree of understanding we have of the basic processes. I would say that we are far behind where terrestrial weather is as far as our understanding of the fundamental basic processes. We are being surprised all the time by what the Sun does and how the Earth and the Earth's environment respond. So I think there is a much closer coupling in many respects between NASA basic research and the needs thereof and what can be transitioned into an operational state.

I would say that therefore, to go to the second part of your question, it is probably more crucial to have close cooperation between agencies in this developing field than it is where the physics are sort of cut and dried and so again, I am encouraged by the fact that space weather, the necessity to understand this complex system, is making the agencies work more closely and cooperatively. I just think that there is more that can be done and I think that—my hope is that the decadal survey will be a catalyst to make this work even better and that there will be more coordination of, let us say, the basic research, the aspirations of that research, the funding that is necessary to transition, but I think it is really going to require that all players work in an orchestrated way to try to make this the most efficient, effective, especially when we look at how limited the resources are going to be over the next years. This has to be done very efficiently and effectively.

Ms. EDWARDS. Thank you. You know, Mr. Chairman, one thing that we didn't have a chance to get actually on the record was not just the impacts to us as civilians in this environment but what the impacts are on our critical national infrastructure that is related to national security and the importance of strengthening what we are doing right now so that we don't have any gaps in understanding space weather and its impact and so that over the long term that we are considering all of our infrastructure in this environment. Thank you.

Chairman PALAZZO. Thank you, Ms. Edwards.

I thank the witnesses for their valuable testimony and the Members for their questions. The Members of the Subcommittee may have additional questions for the witnesses, and we will ask you to respond to those in writing. The record will remain open for two weeks for additional comments and statements from Members.

On a related note, Ms. Furgione, this Committee has several outstanding letters and requests sent to NOAA regarding the National Weather Service over the last few weeks. These include the mismanagement of NWS budget and funding and questions about a review of your agency's handling of Superstorm Sandy. I would ask for your commitment that these requests for information are fully responded to by the end of the calendar year. Can we receive your assurance that that will be done?

Ms. FURGIONE. Yes, sir.

Chairman PALAZZO. Well, thank you very much.

The witnesses are excused and this hearing is adjourned.

[Whereupon, at 11:04 a.m., the Subcommittee was adjourned.]

Appendix I

ANSWERS TO POST-HEARING QUESTIONS

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Daniel Baker

Questions for the Record
Dr. Daniel Baker

From Chairman Palazzo

National Priorities for Solar and Space Physics Research and Application for Space Weather Prediction

Space and Aeronautics Subcommittee Hearing
November 28, 2012

1. Can you elaborate on the survey's recommendations to multi-agency collaboration? Do you have any recommendations on how best to manage a multi-agency research program to ensure effective utilization of scarce resources that is not duplicative? Would it be beneficial to pool resources across agencies and manage such a program out of one coordinating body?
2. Do you have specific observations related to the effectiveness of coordination between NASA as a research agency and NOAA s an operational agency with regards to space weather?

Response to Chairman Palazzo

Space weather refers to conditions on the Sun and in the space environment that can influence the performance and reliability of spaceborne and ground-based technological systems and can endanger human life or health. Programs that are relevant to the observation and prediction of space weather events exist within several federal agencies and they are carried out largely without duplication of effort. However, the decadal survey committee found the existing ad hoc collaborative approach to providing space weather-related capabilities to be ill-suited to meeting projected national needs. In Chapter 7 of our report, we articulate a vision for building on today's foundation with an enhanced national commitment by partnering agencies to make continuous measurements of critical space environment parameters. The partnering for observations is analogous to the monitoring of the terrestrial environment being conducted by NASA in collaboration with a number of other agencies such as NOAA and the U.S. Geological Survey (USGS). Anticipating that the criticality of such a program will grow relative to other societal demands, the survey committee envisions NASA as utilizing its unique space-based capabilities as the basis for a new program that could provide sustained monitoring of key space environment observables. Together with existing assets, such as those provided by sensors on NOAA's GOES program, these measurements would provide a comprehensive monitoring base for space weather forecasting.

It is important to emphasize that the problems the committee found with the current management of space weather programs are not the result of ineffective coordination. For example, NASA and NOAA collaborate effectively on many programs related to observations and modeling, in part because of the good communication and collaboration at the scientist-to-scientist level as well as program levels. Rather, it is that agency roles and responsibilities are not well aligned with resources. NASA research satellites such as ACE, SOHO (with ESA), STEREO, and SDO, which are designed for scientific studies, have over the past decade or more provided critical measurements essential for specifying and forecasting the space environment system, including the outward propagation of eruptive solar events and solar wind conditions upstream from Earth. Although these observational capabilities have become essential for space environment operations, climatological monitoring, and research, NASA currently has neither the mandate nor the budget to sustain these measurements into the future.

Questions for the Record
Dr. Daniel Baker

From Representative Dana Rohrabacher

National Priorities for Solar and Space Physics Research and Application for Space Weather Prediction

Space and Aeronautics Subcommittee Hearing
November 28, 2012

1. In your report, you recommended, "NOAA should establish a space weather research program to effectively transition from research to operations." How can NOAA avoid duplication and leverage expertise from different agencies, industries, and universities?

Response to Representative Dana Rohrabacher

The transition of research to operations requires a broad range of activities, and the intent of the recommendation to NOAA is to complement and build on the work of other agencies, industries, and universities. In NOAA, the mission of the Space Weather Prediction Center (SWPC) is "to deliver space weather products and services that meet the evolving needs of the nation." As noted in Chapter 4 of the decadal survey report, our committee believes that to carry out that mission, "a level of research expertise is needed [within NOAA] to work together with its partners to provide professional forecasts and products, to define requirements, to understand possibilities for supporting customer needs, and to make wise and cost-effective choices about new models and data to support space weather customers."

To take advantage of new discoveries and developments from agencies such as NASA and NSF, and the university research they support, and to make wise and cost-effective decisions about how to invest resources, NOAA needs scientists who are knowledgeable about relevant agency, university, and industry activities; the broad heliophysics discipline; satellite and ground-based observations; modeling techniques; and international space science developments. These research scientists, who also work together with NOAA's forecasters and customers, will not duplicate effort in other organizations, but will fill a much needed gap in the transition of research to operations. There are needs for NOAA to support, manage, and carry out focused research; test and validate numerical codes and forecast techniques; develop metrics; and communicate back to the research community what is needed in terms of models and data. While NOAA SWPC already supports an active program for the transition of research to operations, the efforts need to be sustained and grown to take advantage of new opportunities called for in the survey and to better support those dependent on space weather services. These efforts require a NOAA space weather research program that includes a workforce of those actively involved in all facets of the research community.

Questions for the Record
Dr. Daniel Baker

From Ranking Member Jerry Costello

National Priorities for Solar and Space Physics Research and Application for Space Weather Prediction

Space and Aeronautics Subcommittee Hearing
November 28, 2012

1. What are the key challenges for transitioning basic solar and space physics research into tools that can be accessed by users and applied to operations?
    a. To what degree are current Federal agency activities coordinated, including funding and plans for space weather, and how effective is that coordination?
2. To what extent can operational space weather monitoring be carried out by the private sector? What are the pros and cons and the risks, if any, involved in transferring part or all of this responsibility to the private sector in support of operational space weather prediction?

Response to Ranking Member Jerry Costello

1. Federal agency activities are presently coordinated by means of the National Space Weather Program (NSWP), which is administratively located within the Office of the Federal Coordinator for Meteorology (OFCM). The NSWP structure is comprised of two major elements, the executive National Space Weather Program Council and the subordinate Committee for Space Weather (CSW), both of which are staffed by member agencies. The role of the NSWP in its present form is to exchange information with the objective of utilizing synergies between agencies to more effectively address national needs in Space Weather. The NSWP has no — and is not intended to have — budgetary authority over agencies, either collectively or individually.

Despite striking advancements over the past decade, scientific understanding of space weather phenomena and our capacity to make reliable predictions of space weather events lags considerably in comparison to similar understanding and forecast capability for Earth's terrestrial weather. Many fundamental scientific problems still require solutions if we are to develop the necessary solid scientific underpinnings of a highly capable national space weather warning and protection capability. Consequently, the main focus of the decadal survey has been on scientific research, which is both exciting and directed at resolving key deficiencies of our present scientific understanding. It is essential that this scientific research be conducted.

In addition to research, however, the decadal survey notes the lack of national planning for the long-term provision of measurements, which, to-date, are often derived from limited-life scientific platforms. Current observations need to be continued, but the survey committee concluded that a major, new program is required urgently ("Space Weather and Climatology–SWaC") to provide critical measurements and developmental activities into the future. A SWaC-like program requires a new level of interagency coordination and cooperation, with new budgetary authority. The survey hence called for elevation and re-chartering of the NSWP at an appropriately elevated level of the federal government and made the following recommendation: "*...to coordinate the development of this plan [for enhanced space weather capabilities], the National Space Weather Program should be rechartered under the auspices of the National Science and Technology Council and should include the active participation of the Office of Science and Technology Policy and the Office of Management and Budget. The plan should build on current agency efforts, leverage the new capabilities and knowledge that will arise from implementation of the programs recommended in this report, and develop additional capabilities, on the ground and in space, that are specifically tailored to space weather monitoring and prediction.*"

2. When thinking about public-private roles for "operational space weather monitoring," it is useful to consider whether there are analogies to operational terrestrial weather monitoring. In fulfilling its mission of providing guaranteed timely and reliable weather prediction information to the nation, NOAA's National Weather Service relies on measurements that, from space, are primarily made by instruments on government-procured and government-operated spacecraft. Because of its potential to cause severe damage to vulnerable and critical national assets such as the electrical grid, space weather shares with terrestrial weather the objective of delivering forecasts that are both timely and highly reliable.

However, in contrast to terrestrial weather, space weather is scientifically immature, necessitating the continuous influx of new scientific knowledge and technological development. At least at first glance, the acquisition of space weather data appears even less well suited than terrestrial weather monitoring to the kind of routine approaches that seem amenable to a commercial approach. Under these circumstances, it is challenging to identify a clear business case in a rapidly evolving field, and the survey did not recommend a commercial basis for routine space weather monitoring. However, it would be useful to have additional dialog with the private sector to understand better possible business cases and possibilities for commercial solutions as scientific knowledge advances in the course of the next decade.

The decadal survey committee did emphasize two key roles that commercial entities play and can play in space weather data acquisition and space weather forecasting. First, even today, a fledgling commercial enterprise collaborates with the government to provide tailored forecasts for their customer community. There is significant potential in expanding these partnerships and ensuing value to the nation in receiving the specialized information developed by commercial space weather providers. Second, the survey emphasized the potential to utilize available or excess capacity on commercial satellites to accommodate space physics and space weather instrumentation. These secondary or "hosted payloads" can be both timely and very cost effective; the Iridium constellation and its hosted AMPERE (Active Magnetosphere and Planetary Electrodynamics Response Experiment) payload is a notable example.

Iridium is a constellation in low-Earth orbit. Space weather payloads on commercial platforms, such as geosynchronous communication satellites, can also be a cost effective way to obtain a number of essential space weather measurements. Hence, the SWaC program as described in the survey envisions a blend of traditional government-only and innovative commercial-government hosted-payload approaches as the optimal, flexible, and long-term strategy to meet the nation's space weather data needs.

Questions for the Record
Dr. Daniel Baker

From Representative Donna Edwards

National Priorities for Solar and Space Physics Research and Application for Space Weather Prediction

Space and Aeronautics Subcommittee Hearing
November 28, 2012

1. The Department of Defense (DOD) is among the major users of heliophysics research and models to inform space weather prediction. Could you summarize why improving space weather prediction is important for the DOD and the overall national security community? What are the impacts of space weather on our critical national infrastructure that is related to national security?
2. Given the interagency and multidisciplinary nature of research in solar and space physics, how can affected Federal agencies and Congress monitor progress on the implementation of the recommendations in the National Research Council's (NRC) decadal survey on solar and space physics?
3. The NRC's solar and space physics decadal survey discusses the importance of both space-based and ground-based research in solar and space physics. How will the National Science Foundation's ground-based research program and facilities, particularly the Advanced Technology Solar Telescope, contribute to fulfilling the scientific goals of the decadal survey?
4. The need for "strategic rebalancing" of NASA's heliophysics program is a theme in the National Research Council's decadal survey report. What contributed to a loss of balance and what is needed to restore the number of small and medium-class missions to the level recommended in the decadal survey?

a. In addition, given that the decadal survey acknowledges that most of the NASA heliophysics budget, as projected for 2013-2017, is "locked in" to existing plans, what are the options for implementing the recommended strategy?
b. What is the anticipated scientific return that would result from rebalancing and what are the implications should the rebalancing not occur?

5. In response to Member question during the hearing, you mentioned the need for a follow-on study to look more closely at issues related to an expanded role for NASA in space weather observations. Please elaborate on what key issues, in your view, such a study should examine.

Response to Representative Donna Edwards

1. The Department of Defense (DOD) is both a user and a supplier of space weather information. The primary DOD "customers" are organizations that provide or use geolocation, communications, navigation, space operations, and space object tracking services.[1] All of these critical functions would benefit from an improved forecast capability. In particular, the DOD's primary space weather concern is the state of the ionosphere as it impacts communications, navigation, and targeting operations.[2]

The U.S. Strategic Command, which is the operator of the DOD's space systems and services, is assigned the responsibility to protect the space assets of the military, the intelligence community, the civil space assets, and the assets of allies. To fulfill that responsibility requires that the US Air Force maintain space situational awareness. That awareness includes monitoring the space environment. Given sufficient warning, space assets can be protected against disruptive solar events; situational awareness is also needed to aid in understanding whether a disruption in satellite operations is the result of deliberate interference or a naturally-occurring space weather-related event.

2. Progress in implementation of the decadal survey recommendations can be monitored in many ways. Within a year after publication of the survey, the sponsoring agencies provide the National Research Council with their own self-assessment. The annual agency budget submissions also frequently reference the decadal survey, and Congress and officials testifying at the annual budget hearings also may be requested to address issues related to survey implementation. The NRC also has a role to play in assessing progress in implementation of the survey: per language in the NASA Authorization Act of 2005, the NRC provides a "midterm assessment" of the decadal survey that is issued approximately 5 years following publication of the survey. With the publication last summer of the midterm assessment of the Earth science decadal, the NRC has now completed assessments of its astronomy and astrophysics survey and each of the initial decadals in Earth science and applications from space, planetary science, and solar and space physics.

3. NSF ground-based solar and space physics facilities, which are managed within two of its divisions, are key existing elements of what the survey refers to as the Heliophysics Systems Observatory. The Astronomy Division of the Mathematics and Physical Sciences Directorate manages the National Solar Observatory (NSO), with ongoing synoptic observations and the ATST under construction. It is also the home of the National Radio Astronomy Observatory, which includes solar observational capability. The Atmospheric and Geospace Sciences Division (AGS) of the Geosciences Directorate manages the National Center for Atmospheric Research (NCAR) and its High Altitude Observatory (HAO), which supports a broad range of research from Sun to Earth and operates the Mauna Loa Solar Observatory.

---

[1] National Research Council. *Severe Space Weather Events—Understanding Societal and Economic Impacts: A Workshop Report*. The National Academies Press, Washington, DC, 2008. Available at: http://www.nap.edu/catalog.php?record_id=12507.

[2] *Report of the Assessment Committee for the National Space Weather Program*, FCM-R24-2006, Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM), June 2006, page 12. Available online at: http://www.nswp.gov/nswp_acreport0706.pdf.

AGS also supports the SuperDARN coherent scatter radar system and four large incoherent-scatter radar facilities, including the Arecibo Radio Observatory, which remains the largest aperture in the world for astrophysical, planetary, and atmospheric studies. University-based observatories are also funded by both the NSF and NASA, and USGS operates ground-based magnetic observatories that are used for many purposes, including space weather operations.

When it begins operation in 2018, the 4-meter ATST will be, by far, the largest optical solar telescope in the world. It will be revolutionary in the capabilities it will provide to measure the dynamics of the magnetic field at the solar surface down to the fundamental density length scale. It will be able to remotely sense coronal magnetic fields where they have never been measured. Funding for its operations and analysis needs to be identified to fully realize this investment. In particular, ATST requires adequate, sustained funding from NSF for operation, data analysis, development of advanced instrumentation, and research grant support for the ATST user community. The survey report recommends a significant increase in funding allocation to properly operate and to realize the full and remarkable scientific potential of the ATST.

Important ground-based research is also accomplished through mid-scale research projects that are larger in scope than typical single principal investigator-led projects (like those funded by NSF's Major Research Instrumentation line) and smaller than facilities (such as those developed under NSF's Major Research Equipment and Facilities Construction line). The Advanced Modular Incoherent Scatter Radar (AMISR) is an example of a mid-scale project widely seen to have transformed research in ground-based solar and space physics. While different NSF directorates have programs to support unsolicited mid-scale projects at different levels, these may be overly prescriptive and uneven in their availability, and practical gaps in proposal opportunities and funding levels may be limiting the effectiveness of mid-scale research across the foundation. It is unclear, for instance, how projects like the AMISR would be initiated and accomplished in the future, as no budget line is available that matches this scale of facility development.

Mechanisms for the continued funding of management and operations at existing mid-scale facilities are also not entirely clear. In addition, there is a need for a means of funding mid-scale projects, many of which have been identified by the survey as cost-effective additions of high priority to the overall program. These include the Frequency Agile Solar Radiotelescope (FASR), the Coronal Solar Magnetism Observatory (COSMO), and several other projects exemplifying the kind of creative approaches necessary to fill gaps in observational capabilities and to move the survey's integrated science plan forward. A mid-scale funding line will have major impact on conducting science at ground-based facilities, and it would rejuvenate broadly utilized assets by taking advantage of innovations to address key scientific challenges. Our report includes a recommendation for a new, competitively-selected mid-scale funding line at NSF.

4. The balance among small (Explorer-class), medium-, and large-class missions in NASA's Heliophysics division has been affected by several factors, notably a substantial reduction in the Explorer-class missions, which in turn resulted from substantial decreases to the planned budget for NASA's Science Mission Directorate.[3] A careful analysis of historical NASA spending shows that at least $980

[3] The following is from a Congressional Research Service Report for Congress: "NASA's activities in space science and earth science were merged into the Science Mission Directorate (SMD) in 2004. On several occasions in 2005, [then NASA Administrator] Dr. [Michael] Griffin said that he would not take money from NASA's space science, earth science, or aeronautics programs to pay for the exploration vision. (This pledge did not include microgravity science activities, such as research aboard the ISS.) *Nevertheless, the FY2007 request takes $3.1 billion from SMD over the five-year period FY2007-2011 relative to projections in the FY2006 budget* [emphasis added]. Most of that (about $2 billion) would be used to cover a shortfall in the space shuttle and ISS budgets. Consequently, the requested budget for SMD increases by 1.5 percent in FY2007, and 1 percent in the subsequent four years, less than the projections in the FY2006 budget and less than the rate of inflation." From Daniel Morgan and Carl E. Behrens, "National Aeronautics and Space Administration: Overview, FY2007 Budget in Brief, and Key Issues for

million was removed from the Explorer program in the years 2005-2011 compared to the projections that accompanied the president's 2004 budget request. This meant that a highly successful and highly productive NASA program was reduced dramatically to pay for other NASA programs. Such "raiding" of the Explorer budget was, in my view, shortsighted and very misguided. With the cutting in half of the Explorer funding line—the one demonstrated program for university scientists and engineers to design, build, and operate small spacecraft—was greatly diminished. New proposal opportunities were dramatically reduced for several years with the slashed Explorer budget plan. At least as importantly, NASA had to interrupt the key pipeline of training for the next generation of engineers and hardware-educated scientists who can actually work on major space programs in the future. In retrospect, this budgetary set of decisions has been catastrophic for the universities remaining in space science.

Restoring programmatic balance in NASA's Heliophysics program is a key theme of the survey report. The committee's recommendations in this regard are informed by the recognition that many of the outstanding problems in solar and space physics require an integrated observational approach that can achieve progress across the coupled domains that define the entire field. Our strategy builds on existing and planned programs, optimally deploys recommended new assets at an appropriate cadence, and includes actions and decisions that should be taken in the event that the expected funding profile cannot be attained, or conversely if it is augmented.

Over the past decade, the number of large missions has increased at the expense of medium and small missions (Figure 6.2 from our report). By implementing the committee's proposed program (Figure 6.1), the balance between mission size and enabling research is restored. As shown in Figure 6.3 from our report, at the beginning of the 2013-2024 decade large missions from both the LWS and STP lines dominate the budget. By the end of the decade, a balance between large, mid-sized, Explorer and enabling assets (baseline research plus DRIVE) has been achieved. The phasing that leads to this rebalance is implemented based on the priorities accorded to the elements of the core program. During the early part of the decade, when there is very little flexibility in the NASA heliophysics program, the focus is on the completion of the implementation of existing missions, as well as on maintaining the baseline level of enabling research programs and Explorers. The first new recommendations of this survey to be acted upon pertain to DRIVE. Early implementation of DRIVE ensures the fastest possible return on new investments for the decade (Figure 6.4).

Congress," CRS Report for Congress, Updated June 23, 2006. Available at: http://www.fas.org/sgp/crs/space/RS22381.pdf.

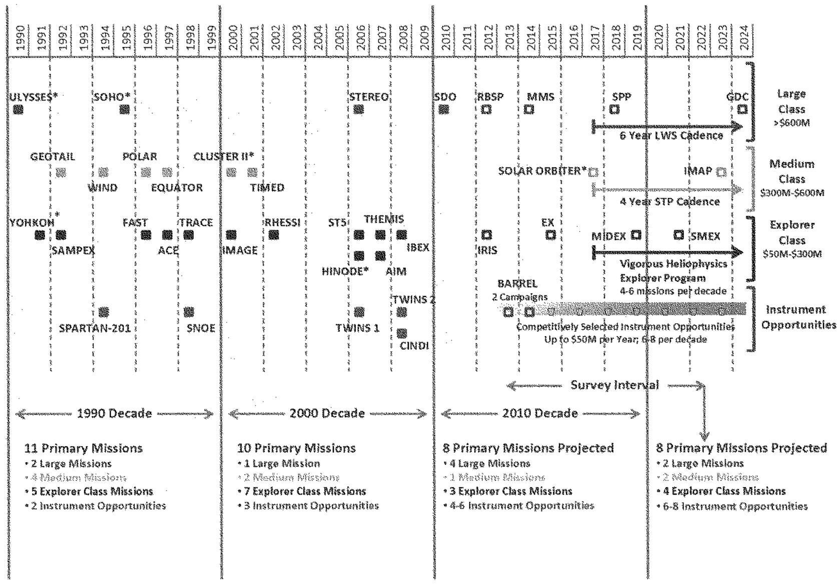


FIGURE 6.2 NASA mission sequence since 1990 by launch year and mission class. The strength of the heliophysics program over the past two decades has been the regular cadence of missions in a variety of sizes. It can be seen that the 1990 and 2000 decades each had 13 missions with the Medium and Explorer Class categories having 9 missions in each decade. A trend toward a loss of balance can be seen in the 2010 decade where the mission complement has tipped toward fewer missions with a bias toward the Large category. A key objective for the next survey interval is to restore the number of Medium and Explorer class missions such that, in combination with competitively selected Instrument Opportunities on hosted payloads (MOOs), a higher cadence can be achieved that is capable of maintaining the vitality of the science disciplines. Funding constraints affect the restoration and rebalance of the programs such that realization of the strategy cannot begin until after 2017 (Figure 6.1). Missions denoted by an asterisk (*) demonstrate the importance of international collaborations where the heliophysics community has a long, active and very fruitful mission history. Open boxes indicated missions that that are in development, or are planned, but have not yet flown.

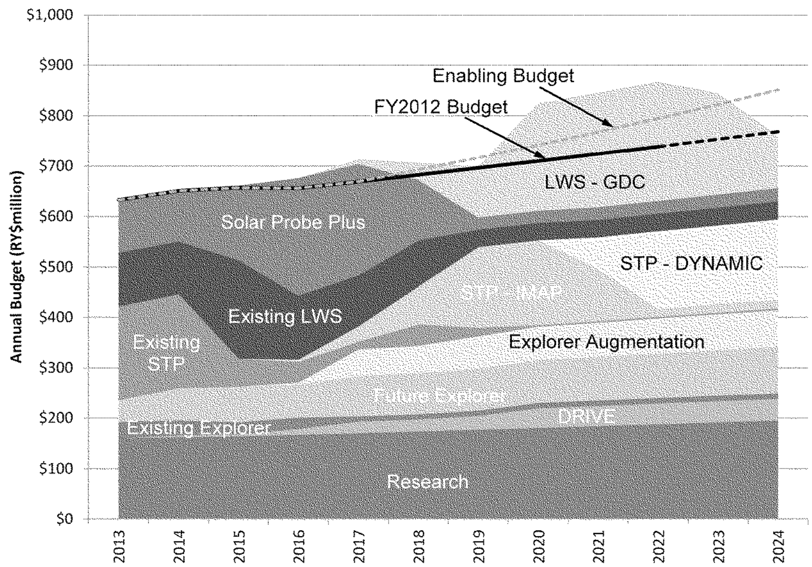


FIGURE 6.1 Heliophysics budget and program plan by year and category from 2013 to 2024. The solid black line indicates the funding level from 2013 to 2022 provided to the committee by NASA as the baseline for budget planning, and the dashed black line extrapolates the budget forward to 2024. After 2017 the amount increases with a nominal 2 percent inflationary factor. Through 2016 the program content is tightly constrained by budgetary limits and fully committed for executing existing program elements. The red dashed "Enabling Budget" line includes a modest increase from the baseline budget starting in 2017, allowing implementation of the survey-recommended program at a more efficient cadence that better meets scientific and societal needs and improves optimization of the mix of small and large missions. From 2017 to 2024 the Enabling Budget grows at 1.5 percent above inflation. (Note that the 2024 Enabling Budget is equivalent to growth at a rate just 0.50 percent above inflation from 2009.) GDC, the next large mission of the LWS program after SPP, rises above the baseline curve in order to achieve a more efficient spending profile, as well as to achieve deployment in time for the next solar maximum in 2024. The heliophysics mission lines are labeled as follows: LWS, Living With a Star missions; STP, Solar-Terrestrial Probes; and EXP, Heliophysics Explorers.

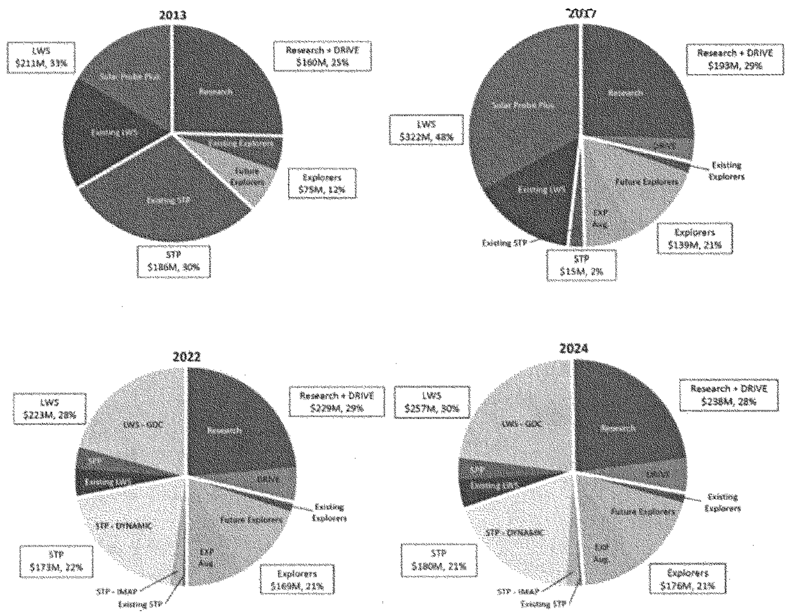


FIGURE 6.3 Effects of strategic rebalancing. The pie charts, above, illustrate the evolution of program balance among four core program elements as the survey-recommended plan is implemented over the survey interval, 2013-2002, plus two years. The charts reflect that much of the NASA heliophysics budget from 2013-2017 is already "locked in." The year 2017 is effectively the start to an "enabling trajectory." An important result apparent in 2017 is the effect of implementing the DRIVE initiative and the restructured Explorer program. It can be seen that the sum of Research + DRIVE and Explorers (R+D+E) increases from approximately 37 percent to the intended value of 50 percent of the total program budget.

The year 2022 represents the endpoint of the survey interval and demonstrates that the overall rebalancing of the program has occurred with the maintenance of the 50 percent R+D+E funding but also a sustainable division between the STP and LWS program with the remaining 50 percent of the budget. The year 2024 represents the planned endpoint of the rebalancing initiative as well as the legacy profile for the next survey. An important legacy result is how the program stably maintains the balance moving forward from 2022. Note that the 2022 and 2024 budgets are represented by the "Enabling Trajectory" budget and do not include the GDC bump which is considered a plus-up from the base program.

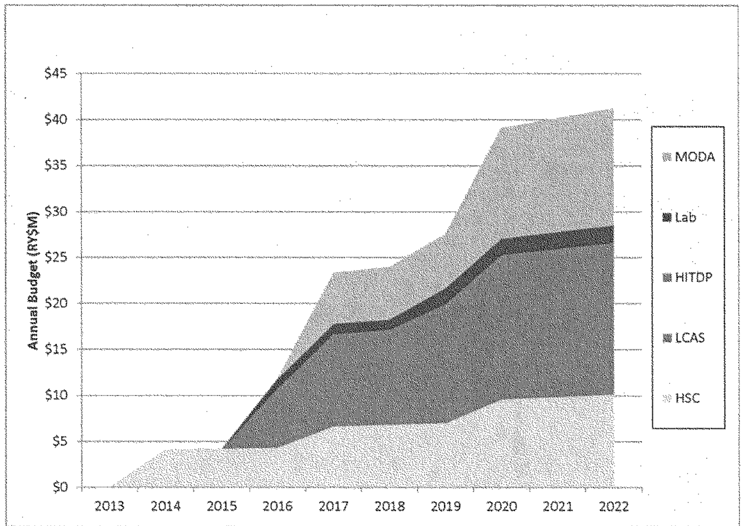


FIGURE 6.4 NASA DRIVE implementation. For the cost of a small mission, the DRIVE initiative recommends augmentations to NASA mission-enabling programs that have been carefully chosen to maximize the effectiveness of the program overall. Six of the DRIVE sub-recommendations have cost impact for NASA. Of these, *NASA Mission Guest Investigator* would require a cost allocation within STP and LWS missions of ~2 percent of total mission cost for a directed guest investigator program. The other five are: NASA LCAS Microsatellites (LCAS), MO&DA augmentation (MODA), Heliophysics Science Centers (HSCs), Heliophysics Instrument and Technology Development Program (HITDP), and Multi-agency Laboratory Experiments (Lab). They have been phased with a slow start because of budget constraints, and in sequence that allows for time to develop and ramp up new programs. Note that the MO&DA augmentation begins in 2016, at a time when the SDO will have moved out of prime mission, adding greatly to data covered by the general GI program. Implementation of the NASA portion of DRIVE ramps up by 2022 to an augmentation to existing program lines that is equivalent to approximately $33 million in current (2013) dollars. (In the developing this figure, the survey committee assumes a 2.7 percent rate of inflation, which is what NASA currently assumes as the inflation factor to be used for its new starts.)

5. The availability of information that is needed to monitor and forecast space weather events, and to inform decision-makers considering options to protect elements of an increasingly technologically based society that are vulnerable to severe space weather events, rests on a number of ad hoc agency relationships and what I would categorize as good fortune. For example, informed by the views of a broad swath of the solar and space physics community, the previous (2003) NRC decadal survey in solar and space physics had as its highest priority for NOAA the development and launch of a successor to the ACE spacecraft. From its halo orbit at the first Lagrangian point, some 1 million miles from Earth on a line to the Sun, instruments on ACE provide the earliest (~1 hour) warning of a solar coronal mass ejection that could be directed at Earth. Launched in 1997, ACE was already beyond its design life in 2003; however, it is only within the last year that funding has been identified to support the refurbishment and launch of the DSCOVR spacecraft as a potential stop-gap follow-on.

The difficulty in securing the solar wind measurements made by ACE and the uncertain future[4] of magnetograph and coronagraph measurements, the latter of which are essential for the detection of Earth-bound CMEs, illustrates a larger problem: NOAA is the agency responsible for developing space weather forecasts and warnings; however, except for the critical observations made by the NOAA GOES satellite, much of the data it relies on comes from NASA "research" spacecraft for which there may be no follow-on or operational resilience. The need for a comprehensive strategy to ensure that national needs for space weather information are met was highlighted in our report and Chapter 7 provides an analysis of the observational and forecast capabilities that the survey committee believes are necessary to meet evolving needs for space weather and space climatology monitoring and prediction.

The 2012 decadal survey recommended that an assessment by the space weather community be carried out to "evaluate new observations, platforms, and locations that have the potential to provide improved space weather services", and recommended interagency activities related to space weather be carried out that include a "partnership to plan for a continuity of solar and solar wind observations." A key question that will need to be addressed in any future study is, "What should the United States be doing to understand space weather, mitigate its effects both in space and on the ground, and improve the ability to recover from a major event?" Such a study could consider current and projected needs for space weather warnings to critical infrastructures such as the power grid and lay out options for observing, modeling, predicting, and providing alerts for space weather, and for mitigating and reversing its impacts on important infrastructures.

Possible Items for a Future Study

The most compelling questions in terms of societal impacts of space weather can be very broadly stated as the following:

- What are the real risks of severe societal impacts from space weather?
- What mitigations steps are or can be taken?
- What predictions are available and what is required?

The responsibilities entailed in these questions, however, rest not just with NASA and NOAA, but with a number of key industries and a wide span of federal agencies ranging from NSF to Homeland Security. It is therefore practical think of the questions in terms that allow various organizations to more easily envision their roles. The resulting needs and issues can be roughly categorized as:

a) Improved understanding of space weather,
b) Improved understanding of space weather risks and impacts,
c) Defining space weather monitoring needs,
d) Mitigating or preparing for space weather impacts, and
e) Addressing space weather organizational responsibilities and needs.

A potential study might address some or all of these depending on the desired scope and sponsorship. For example, a study focused only on the current roles of NASA and NOAA might address only a, c, and d, while a broad study focused on critical national needs would likely include a through e.

[4] SOHO, a 2-year mission launched in December 1995, carries a coronagraph, but its operations are scheduled to end in December 2012 (though it is possible that coronagraph measurements could be extended). SDO, its successor does not carry a coronagraph. The STEREO spacecraft carry coronagraphs, but they are also beyond their design life. Furthermore, the spacecraft are drifting to less favorable orientations for detection of Earth-bound CMEs.

Responses by Mr. Charles J. Gay

Questions for the Record
Mr. Charles Gay

National Priorities for Solar and Space Physics Research and Applications for Space Weather Prediction

Space and Aeronautics Subcommittee Hearing
November 28, 2012

From Chairman Palazzo

1. What consideration – if any – does NASA give to operational needs for space weather as decisions about the next suite of research programs are being made?

From Representative Dana Rohrabacher

1. Having conducted 74 successful missions, the NASA Explorer spacecraft carries the longest running series of scientific investigations. The solar and space physics community has done much of its best research with Explorer missions, usually within cost and schedule constraints. It's been three years since the last Medium class Explorer mission. Now, the decadal survey recommends restoring medium-class Explorer missions to enable significant scientific advances.
   a. Is the availability of an affordable launch vehicle a show stopper in implementing mid-size class mission? If so, how can we overcome this barrier?
   b. What scientific or mission design trade-offs would be required to remain within the augmented $70 million dollars cost constraint?
   c. What other barriers can impede NASA from implementing mid-size missions?

From Ranking Member Jerry Costello

1. What are the key challenges for transitioning basic solar and space physics research into tools that can be accessed by users and applied to operations?
   a. To what degree are current Federal agency activities coordinated, including funding and plans for space weather, and how effective is that coordination?

2. To what extent can operational space weather monitoring be carried out by the private sector? What are the pros and cons and the risks, if any, involved in transferring part or all of this responsibility to the private sector in support of operational space weather prediction?

From Representative Donna Edwards

1. Given the inter-agency and multidisciplinary nature of research in solar and space physics, how can affected Federal agencies and Congress monitor progress on the implementation of the recommendations of the National Research Council's decadal survey on solar and space physics?

2. To what extent does NASA's data and information on tracking solar storms get transmitted to and used by NOAA and its operations for space weather prediction?

3. What are the pros and cons of an expanded role for NASA in space environment observations, as is proposed in the solar and space physics decadal survey?

Questions for the Record
Ms. Laura Furgione

National Priorities for Solar and Space Physics Research and Applications for Space Weather Prediction

Space and Aeronautics Subcommittee Hearing
November 28, 2012

From Chairman Palazzo

1. Is NOAA considering use of commercial sources for future space weather products? Can you give us examples of where commercial data sources might be available and beneficial?

2. What plans does NOAA have for replacing the Space Environment Monitor suite of instruments that currently fly on the POES satellites but are not part of the planned JPSS constellation? How will this decision impact NOAA's ability to assess space weather in the future?

From Representative Dana Rohrabacher

1. Over the past 7 years since you transitioned the Space Prediction Weather Center to National Weather Service, NOAA has reduced emphasis on applied research in favor of operational space weather forecasting.

    (a) How does NOAA plan to address the NRC's recommendation to do the exact opposite?

    (b) Can this be achieved without increasing the budget or would it require reducing operational space weather forecasting?

From Ranking Member Jerry Costello

1. What are the key challenges for transitioning basic solar and space physics research into tools that can be accessed by users and applied to operations?

2. To what degree are current Federal agency activities coordinated, including funding and plans for space weather, and how effective is that coordination?

3. To what extent can operational space weather monitoring be carried out by the private sector? What are the pros and cons and the risks, if any, involved in transferring part or all of this responsibility to the private sector in support of operational space weather prediction?

From Representative Donna Edwards

1. Does NOAA disagree with any of the recommendations in the National Research Council's solar and space physics decadal survey? If so, which recommendations and why?

2. Given the inter-agency and multidisciplinary nature of research in solar and space physics, how can affected Federal agencies and Congress monitor progress on the implementation of the recommendations of the National Research Council's decadal survey on solar and space physics?

3. In your prepared statement, you say that "NOAA, in consultation with its operational partner, the Air Force, is assessing plans for continuity of such [solar wind] data after DSCOVR. We are evaluating the best value options for continuity for our requirements for solar wind observations and the initiation of operational coronal mass ejection imagery in the post-DSCOVR era." When will that assessment be completed? Please provide a copy of the plan to the Committee on Science, Space, and Technology for the record.

4. To what extent is NOAA positioned to fully receive, use, and apply NASA-collected data and information on tracking solar storms in NOAA's operations for space weather prediction?

5. How would the expanded role for NASA discussed in the solar and space physics decadal survey affect NOAA's activities in space weather prediction?

6. NOAA's FY2013 budget for the National Environmental Satellite Data and Information Service (NESDIS) includes $22.9 million "to continue the refurbishment of NASA's DSCOVR, which will provide solar wind data for geomagnetic storms". The FY2012 budget for the Air Force included funding to provide a launch vehicle for DSCOVR. What is the status of DSCOVR and what is the scheduled launch date? What impact has the CR had on the project?

Responses by Ms. Laura Furgione

Questions for the Record
Ms. Laura Furgione
From Chairman Palazzo

National Priorities for Solar and Space Physics Research and Applications for Space Weather Prediction

Space and Aeronautics Subcommittee Hearing
November 28, 2012

---

1. Is NOAA considering use of commercial sources for future space weather products? Can you give us examples of where commercial data sources might be available and beneficial?

2. What plans does NOAA have for replacing the Space Environment Monitor suite of instruments that currently fly on the POES satellites but are not part of the planned JPSS constellation? How will this decision impact NOAA's ability to assess space weather in the future?

Questions for the Record
Ms. Laura Furgione
From Representative Dana Rohrabacher

National Priorities for Solar and Space Physics Research and Applications for Space Weather Prediction

Space and Aeronautics Subcommittee Hearing
November 28, 2012

---

1. Over the past 7 years since you transitioned the Space Prediction Weather Center to National Weather Service, NOAA has reduced emphasis on applied research in favor of operational space weather forecasting.

   (a) How does NOAA plan to address the NRC's recommendation to do the exact opposite?

   (b) Can this be achieved without increasing the budget or would it require reducing operational space weather forecasting?

Questions for the Record
Ms. Laura Furgione
From Ranking Member Jerry Costello

National Priorities for Solar and Space Physics Research and Applications for Space Weather Prediction

Space and Aeronautics Subcommittee Hearing
November 28, 2012

---

1. What are the key challenges for transitioning basic solar and space physics research into tools that can be accessed by users and applied to operations?

2. To what degree are current Federal agency activities coordinated, including funding and plans for space weather, and how effective is that coordination?

3. To what extent can operational space weather monitoring be carried out by the private sector? What are the pros and cons and the risks, if any, involved in transferring part or all of this responsibility to the private sector in support of operational space weather prediction?

Questions for the Record
Ms. Laura Furgione
From Representative Donna Edwards

National Priorities for Solar and Space Physics Research and Applications for Space Weather Prediction

Space and Aeronautics Subcommittee Hearing
November 28, 2012

---

1. Does NOAA disagree with any of the recommendations in the National Research Council's solar and space physics decadal survey? If so, which recommendations and why?

2. Given the inter-agency and multidisciplinary nature of research in solar and space physics, how can affected Federal agencies and Congress monitor progress on the implementation of the recommendations of the National Research Council's decadal survey on solar and space physics?

3. In your prepared statement, you say that "NOAA, in consultation with its operational partner, the Air Force, is assessing plans for continuity of such [solar wind] data after DSCOVR. We are evaluating the best value options for continuity for our requirements for solar wind observations and the initiation of operational coronal mass ejection imagery in the post-DSCOVR era." When will that assessment be completed? Please provide a copy of the plan to the Committee on Science, Space, and Technology for the record.

4. To what extent is NOAA positioned to fully receive, use, and apply NASA-collected data and information on tracking solar storms in NOAA's operations for space weather prediction?

5. How would the expanded role for NASA discussed in the solar and space physics decadal survey affect NOAA's activities in space weather prediction?

6. NOAA's FY2013 budget for the National Environmental Satellite Data and Information Service (NESDIS) includes $22.9 million "to continue the refurbishment of NASA's DSCOVR, which will provide solar wind data for geomagnetic storms". The FY2012 budget for the Air Force included funding to provide a launch vehicle for DSCOVR. What is the status of DSCOVR and what is the scheduled launch date? What impact has the CR had on the project?

○