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

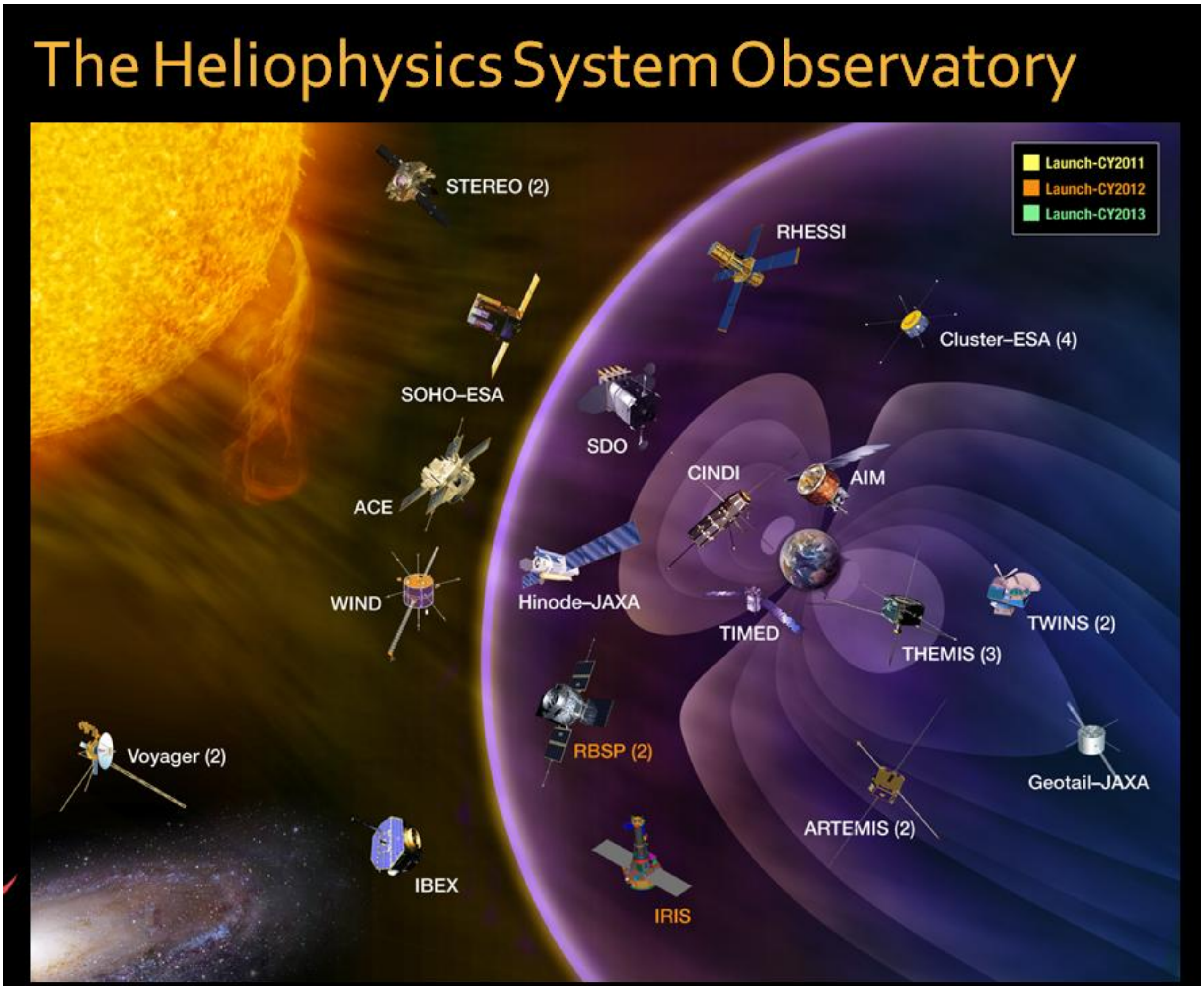


Figure 1. Source – National Research Council

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.

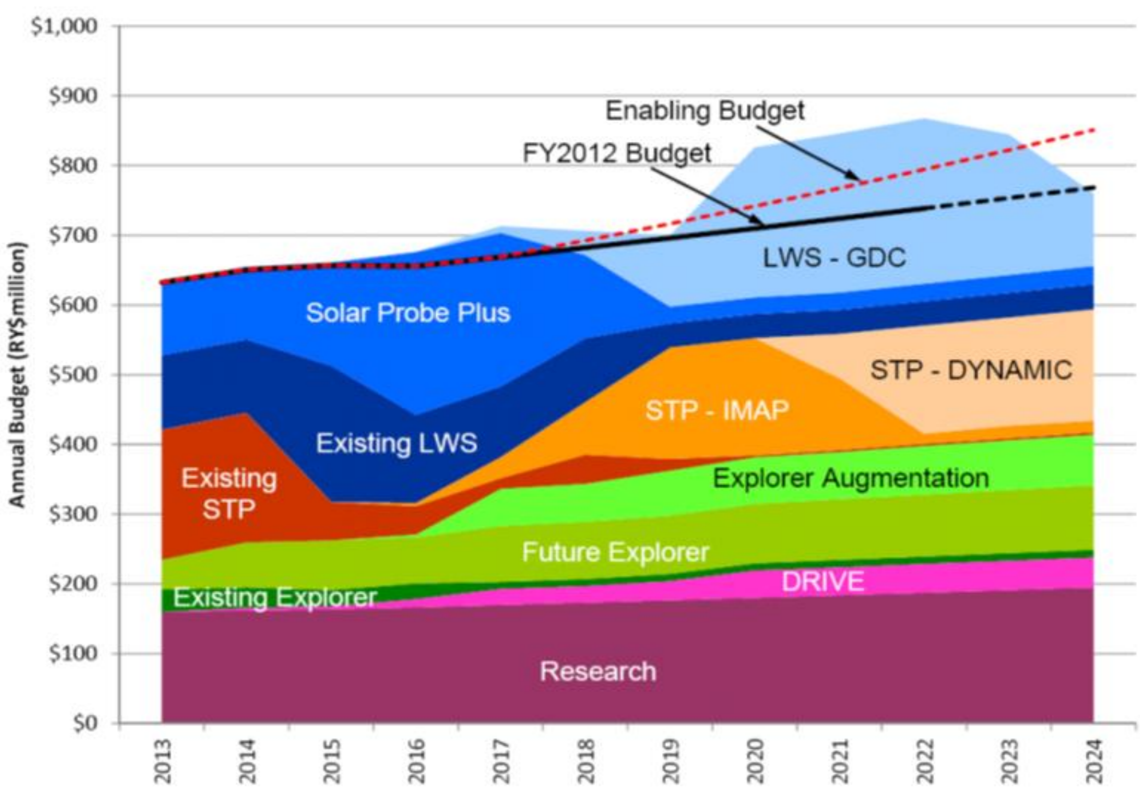
Additionally, the HSO is supported by a system of ground-based observatories and related analysis managed by the National Science Foundation. (A more complete description of the NSF network is described in a section below.)

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.

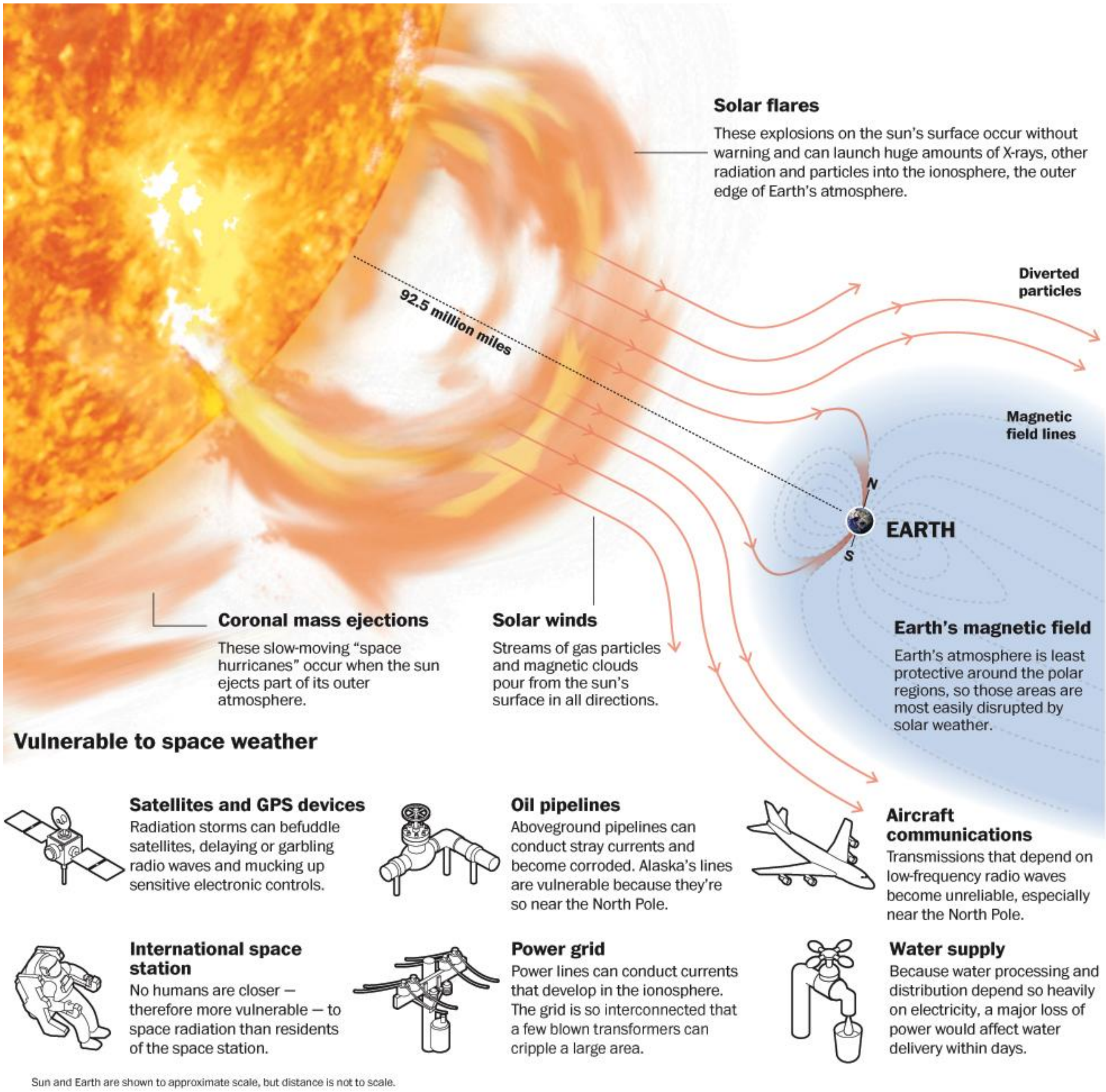


Figure 3: NASA. Bonnie Berkowitz And Alberto Cuadra / The Washington Post. Published on January 23, 2012

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:

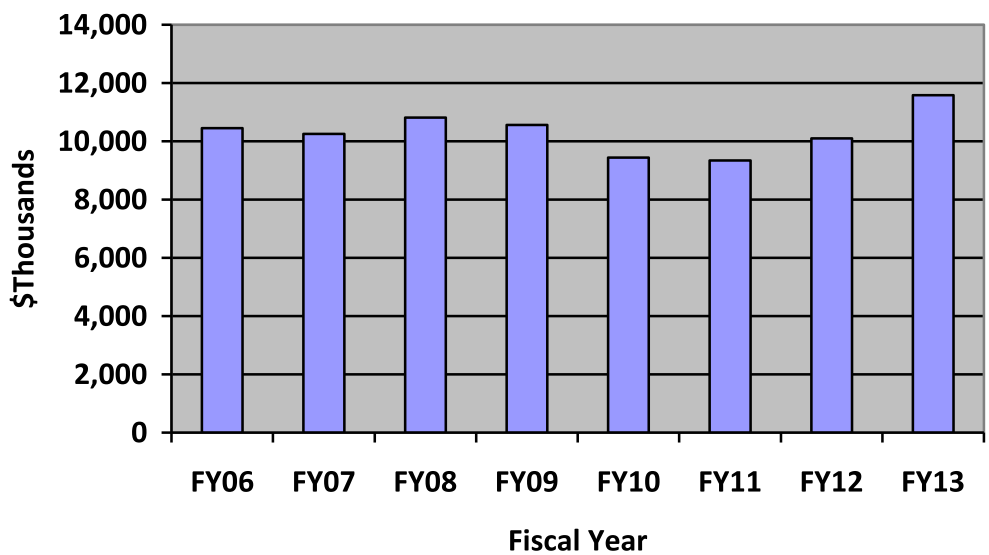
> *The Space Weather Prediction Center (SWPC) is part of the National Weather Service and is one of the nine National Centers for Environmental Prediction. It is the nation's official source of space weather alerts, watches and warnings. SWPC provides real-time monitoring and forecasting of solar and 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.